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THE PRACTICAL UTILIZATION OF REMOTE SENSING TECHNOLOGY FOR  
THE MANAGEMENT AND CONSERVATION OF NATURAL RESOURCES

PART 1: CROP FORECASTING

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FOREWORD

Remote Sensing from Satellites, from its experimental beginnings in the mid-sixties is approaching operational status. This study is aimed at indicating how this technology can be put to practical use on significant problems of global interest and importance.

The objective of this report is twofold: 1) To present a working methodology for the utilization of Remote Sensing technology in the management of Natural Resources; 2) to illustrate this methodology with several practical examples of remote sensing applications.

The study was prepared by Peter A. Castruccio and Harry L. Loats, respectively President and Vice-President of ECOSYSTEMS INTERNATIONAL, INC.

### SUMMARY

Information is a major ingredient in the conduct of human affairs. The technology of remote sensing is the latest development in the search for ever more accurate and timely information at minimal cost.

The technology of remote sensing is a powerful but sophisticated tool. To achieve optimal exploitation, it must be utilized with a sophisticated understanding of its capabilities and limitations, and of the system to which it is applied.

The forecast of agricultural production is an activity of major importance in the management of natural resources. It is practiced in virtually all countries of the world. Timely and accurate forecasts of surpluses or deficiencies allow Governments to plan and implement domestic and foreign policies and actions. Recently developed economic models indicate that even modest improvements in forecast accuracies are potentially worth hundreds of millions of dollars to world consumers. Current methods of forecast vary in scope and sophistication among countries. All are based upon repeatedly sampling the planted acreage and the condition, or status, of the crop. Sampling is effected through voluntary reports from farm operators, and/or through field inspection by specialists in the employ of, or connected with, the central government or its administrative subdivisions.

The product of the computed acreage planted (hectares) times the predicted yield (quintals per hectare) is the estimated forecast of total production (quintals or tons). Because the production is extrapolated from only a small fraction of the crop universe even the best crop forecast methods display inaccuracies of order three to five percent a few months prior to harvest, and upwards of ten percent earlier in the season. Ap-

proximately half the error is (in the U.S.) contributed by inaccuracies in acreage estimation. The current worldwide low levels of stored food staples stress the urgency of improving the forecasts. Improvement is achievable by intensifying current systems, employing more samples and better sampling procedures. The expense involved is significant.

Results from ERTS tests indicate that satellite information can be applied with significant cost advantages to operational crop forecasts. Specifically, satellite information can at present be used to measure crop acreage. Sampling can be as intense as desired, and extend if needed to the entire country or region, with significant improvement in accuracy at relatively low cost.

The measurement of crop condition is more difficult. Further research and tests are needed before satellite data can be operationally applied. Progress in yield estimation is however most encouraging: an operational yield system should become available in the proximate future.

An operational crop forecast system can now be structured and implemented, measuring crop acreage by remote sensing from satellites and employing conventional ground sampling to determine yield. In its next transition this system can be broadened to include both acreage and yield measurements from satellite remote sensing.

Three major options are available for operating such a system:

- 1) procure satellite-derived information from one of the existing (Canada, Brazil, U.S.A.) or planned (Italy) facilities; and contract the interpretation of the information to specialized commercial contractors;
- 2) procure the information as in 1), and install a national data processing facility with trained staff;
- 3) install a satellite Data Reception and a Data Processing facility with their trained staffs.

The choice of remote sensing system must be predicated upon two concurrent economic, or socioeconomic, criteria:

- 1) The economic (or social) value of improving the forecasts must exceed the cost of the system (Benefit/Cost);
- 2) The costs incurred in the establishment of a remote sensing system must be lower, for the same results and coeteris paribus, than those required to improve current ground systems.

The costs and benefits vary significantly among nations, and must be calculated case by case. In general, satellite remote sensing information shows significant economic advantages.

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## SECTION 1

### INTRODUCTION

Information is a major ingredient in the conduct of human affairs: it is especially important in the management of Natural Resources.

Knowledge of next season's crop production affects food prices. The more precise this knowledge, the more efficiently can the resources of farmers, storage facilities, food processing enterprises and investors be allocated.

Knowledge of the runoff from watersheds and of user's demands for water is key to the sizing of hydraulic works: the more accurate the knowledge, the closer to optimum will be the benefit/cost of the design.

Information gathering is as old as civilization: census taking by the Egyptian Pharaohs and the Roman Emperors are universally-known examples. The application of scientific statistical methods, and the institution of formal statistical analysis groups within major Government Agencies dates back to the second part of the nineteenth century. Early methods - - - still in wide use today - - - consisted of sampling events, by voluntary cooperation of economic operators, and/or through surveys by government specialists.

As demands for more accurate information increased, and the costs of manual reporting grew, advanced technology has increasingly been applied to the gathering of data and their compilation into useful information.

For example, the manual reading of raingauges is increasingly being replaced with automated rainfall recording stations: advanced designs convey the readings directly over telephone or radio links. The measurement of riverflow by reading graduated sticks is giving way to automatic, unattended water height recorders. The correlation of the recorded data is trans-

itioning from paper and pencil to desk calculators to computers.

In spite of increased automation, these methods are still tied to the ground surface. They necessarily rely upon sampling point events, in the hope that the sample portrays the situation over the surrounding area. They sample events at discrete intervals, in the expectation that things will not change excessively in the meanwhile.

These hopes and expectations are but imperfectly fulfilled by nature, the data gatherer ideally desires means to sample "everything continuously at very cost". He would like therefore an elevated platform, from which to observe and record all that goes on over the surface below. This is the basic reason for the development of the technology of remote sensing.

One of the potentially most powerful tools towards this end, the airplane, appeared early in the twentieth century. Its application to military information gathering during World War I was rapid and spectacular, to the point where remote sensing from airborne photography is currently a primary means of strategic and tactical information gathering.

This success led, shortly after World War I, to exploring the application of the new technique to the discovery and management of Natural Resource.

Since then, the use of the technique has expanded greatly: currently in the United States, approximately 1.5 million square kilometers of territory are routinely remotely sensed each year by photography from aircraft, for purposes of land use, geological and topographic mapping and certain aspects of crop reporting. At least another one million square kilometers are being surveyed yearly throughout the rest of the world.

The development of advanced sensors in the late forties and fifties multi-spectral photography, radar, infrared -- opened new possibilities: detection of forest fires, discerning of surface temperatures, and

recognition of objects hidden by cloud cover. Their coverage and continuity potential is outpacing the capabilities of the airplane as a carrier. Relatively low speeds and altitudes limit the daily area coverage; bad weather reduces productivity; costs increase directly with the extent of the area surveyed. The next order of magnitude increase towards approaching the ideal "sample everything, continuously, at low cost" was the installation of remote sensors in satellites.

One ERTS picture covers 35,000 square kilometers instead of at most the few hundred achievable from aircraft: in an eight hour "working day", ERTS can sample 2 million square kilometers of the earth's surface, as against the few thousands possible from aircraft. Satellite trajectories are not affected by weather: and, though initial costs are high, subsequent coverage is substantially "free".

These significant advantages must be traded against the lesser resolution achievable from satellites as compared with airplanes. Resolution can and will increase significantly in the future: nevertheless, at this time, remote sensing from satellites must be applied to uses for which resolution is less important than large area coverage.

Three ground rules apply to the structuring of practical applications utilizing satellite surveys.

- 1) Optimal utilization of the data requires sophisticated understanding of the application. This means the availability of personnel who understand the physical and engineering aspects; of competent economists; personnel trained in interpreting the remotely sensed data; equipment and facilities suited to extracting the desired information from this new and sophisticated source of data.

- 2) Final selection of the optimum technique should be based upon

the twin criteria of benefit/cost and cost/effectiveness. The necessary, but not sufficient, benefit/cost criterion assures that the added value contributed by the remotely sensed data exceeds the added cost of procuring and elaborating these data. The cost/effectiveness criterion compares the cost of implementing the application to the same level of performance via remotely sensed data versus conventional methods.

3) A common fallacy worth dispelling is that the technology of remote sensing displaces all methods of conventional data collection. At present this is not so, although it may be possible in the future. For example: remote sensors cannot as yet penetrate deeply beneath the earth's surface. Thus, unless subsurface conditions can be inferred from surface observables, they must be collected via conventional means.

In summary, the strategy for guiding the optimal application of remote sensing is: a) understand the application; b) understand the capabilities and limitations of the technique; c) match the two. The logic of this process is illustrated following for applications of major importance to developed and developing Nations.

## SECTION 2

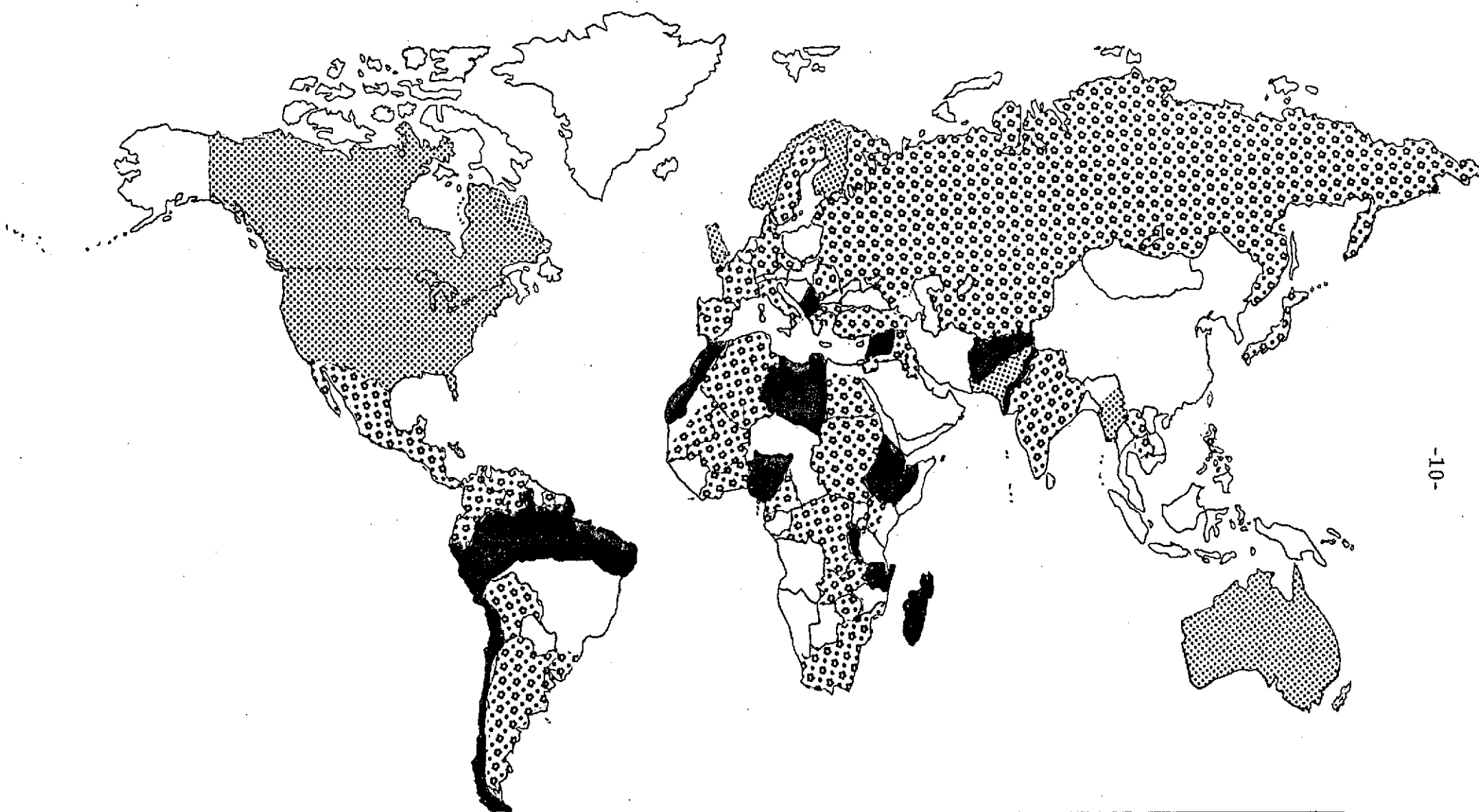
### APPLICATION OF REMOTE SENSING TO AGRICULTURAL CROP FORECASTING

#### 2.1 Significance

The measurement and forecasting of agricultural production are activities of major importance in virtually all countries of the world, as indicated in Figure 1.

Inaccurate forecasts cause agricultural producers to make erroneous production decisions and distort optimal inventory carryover. Consequently, improvements in the accuracy of forecast reduce the social cost of misinformation and hence produce a net increase in social welfare. Precise forecasts obtained sufficiently early permit the formulation of National plans and policies best suited to cope with surplus or scarcity. Good predictions allow agricultural producers to take remedial actions aimed at increasing output, reducing costs, or taking shelter against declining prices caused by overproduction. The earlier this information is available, the greater the spectrum of ameliorative actions permitted and thus the larger the potential benefits.

There is no comprehensive economic theory which exactly quantifies the value of improvements in accuracy of crop forecasting. A principal difficulty is the fact that the modern agricultural commodity market is a "mixed" market exhibiting influences of both a controlled and pure "free" market. It is subject to a vast array of Government controls and decisions. For example, a crop shortfall does not automatically imply that the affected Country will import the difference between its production and internal con-



-10-

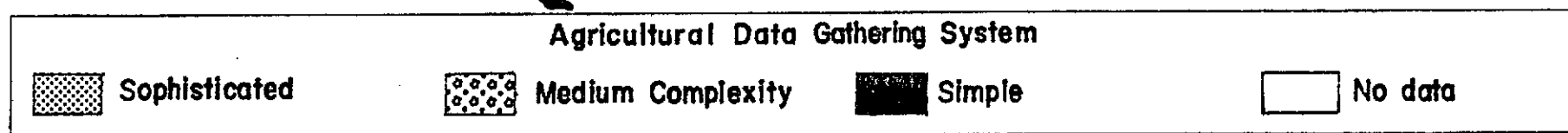


FIGURE I. Distribution of Crop Forecasting Activities

sumption. It may turn instead to alternate policies of commodity substitution, rationing, livestock slaughtering. This relatively unpredictable behavior is not easily amenable to existing economic theories.

A simplified theory, based upon classical economic concepts, of the worth of accurate crop forecasting is illustrated in Figure 2. This theory was developed by Hayami and Peterson using USDA data.

With reference to Figure 2, assume production constant from year to year. If true production in year 1 is  $OQ$  (tons), the corresponding price is  $OP$ .

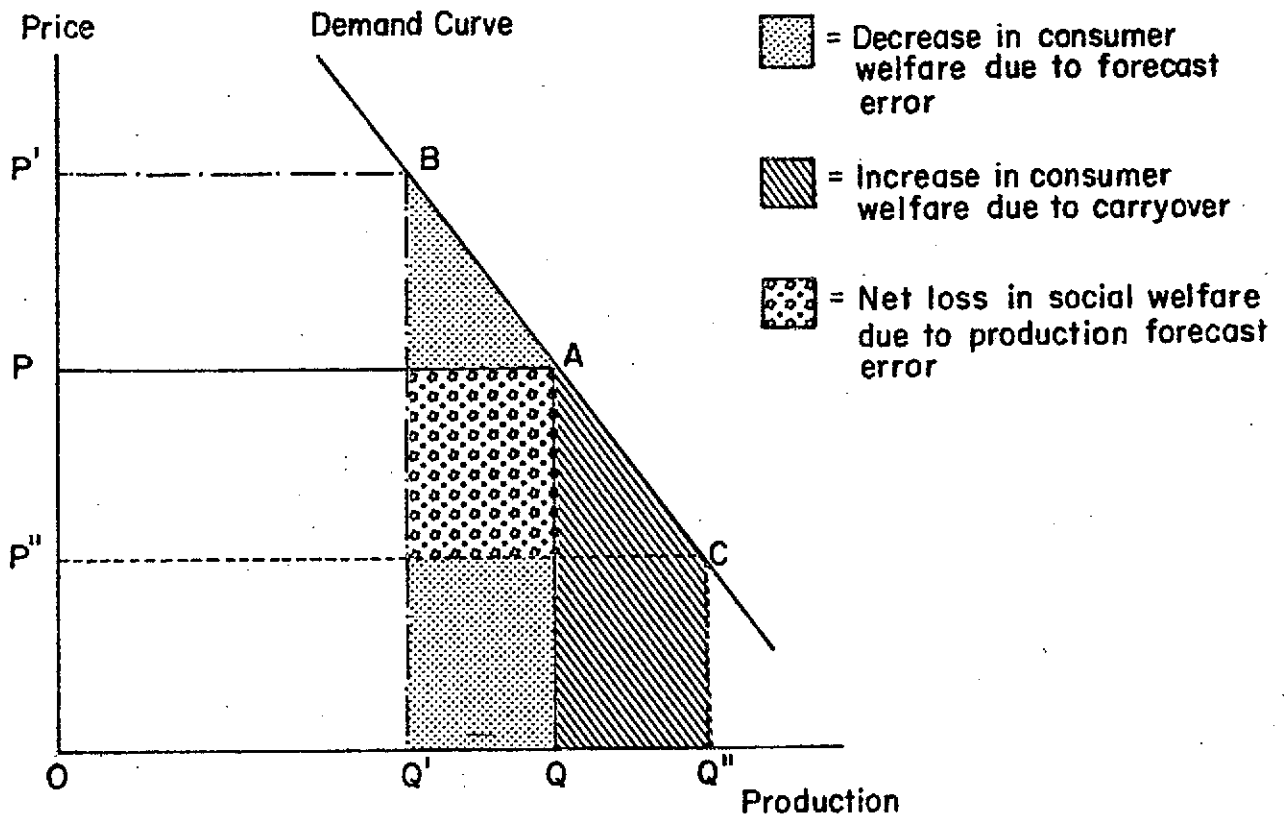
If the forecast erroneously indicates production as  $OQ'$ , the market will bid price  $OP'$ . The community will consume less ( $OQ'$ ) at a higher price ( $OP'$ ). The "consumer welfare" is reduced by the area  $ABQ'Q$ .

Because of reduced consumption, a stock equal to  $OQ'$  is carried over to the second year. The quantity available in year 2 is then  $OQ + OQ' = OQ''$ . The corresponding year 2 price is  $OP''$ . Total consumption is now ( $OQ''$ ), at a lower price ( $OP''$ ). Consumer welfare increases by the area  $ACQ''Q$ .

The net result is a change in consumer welfare, over 2 years, of  $ABQ'Q - ACQ''Q$ . If the demand curve is linear and down-sloping, this change is always a loss, represented by the starred area in Figure 2.

Figure 3 exemplifies the economic loss predicted by this simple theory for selected US crops.

The worth of the agricultural forecast activity is also evidenced by the efforts and resources which are being devoted to it worldwide. Table 1 presents a conservative estimate of the expenditures by World Governments for agricultural data gathering. Additional moneys, not reflected in Table 1, are expended yearly by commodity dealers, traders,



$OQ$  = True Production

$OP$  = Price which would correspond to  $OQ$

$OQ'$  = Forecasted Production

$OP'$  = Price corresponding to estimated production  $OQ'$

$QQ''$  = Quantity carried over to next year

$OP''$  = Price corresponding to next period production  $OQ$  plus stock carryover  $QQ''$

FIGURE 2. BASIC STRUCTURE OF HAYAMI -PETERSON ECONOMIC MODEL

# FIGURE 3

## LOSS DUE TO CROP FORECAST ERROR

(U.S. grain crops after Hayami Peterson)

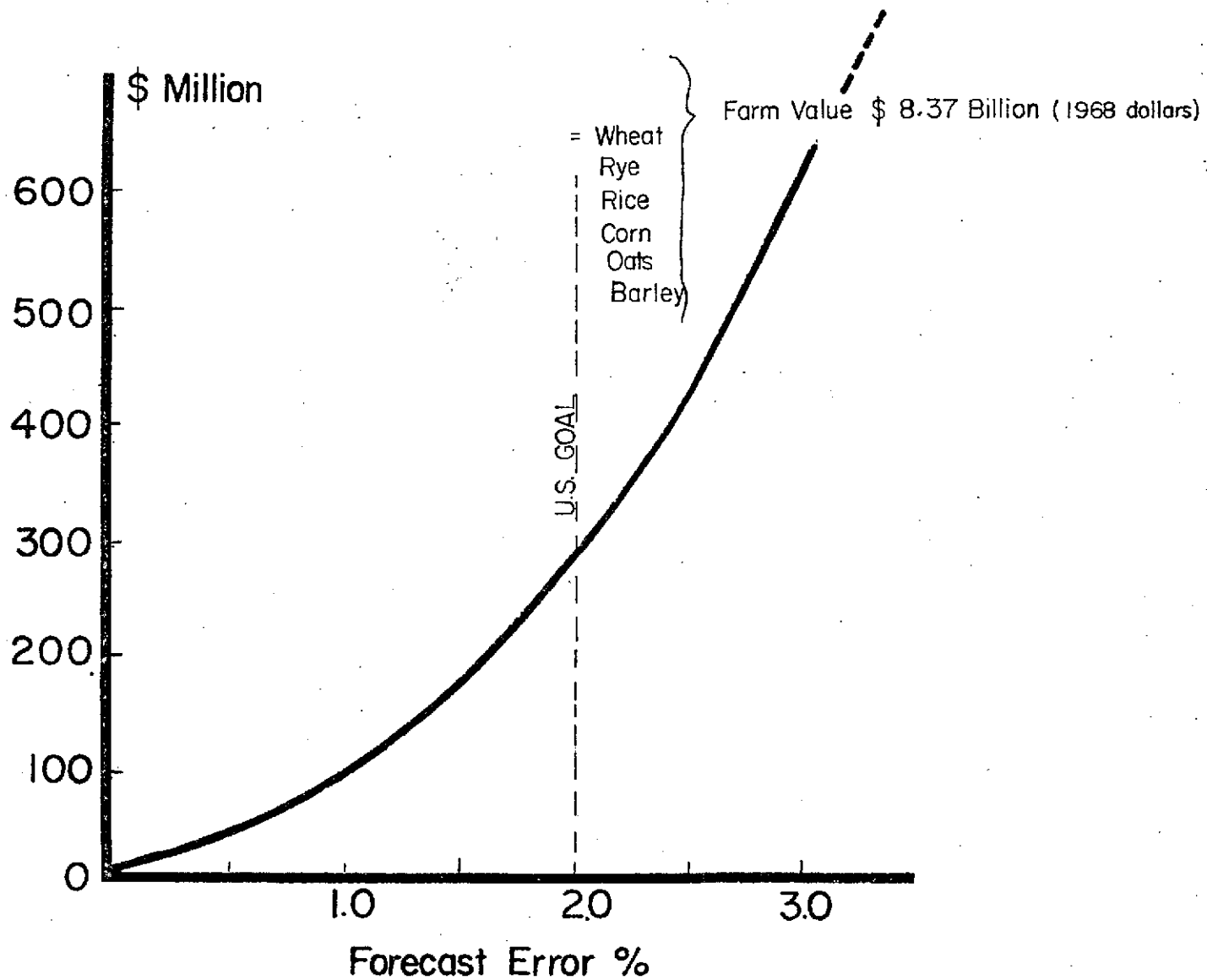


TABLE 1

YEARLY COST OF WORLDWIDE CROP SURVEY/FORECAST

Region	Per Capita GNP Ratio	Weighted Survey Factor	Survey/ Forecast Cost Million U.S. \$
North America U.S. Canada	1 0.084	1 0.7	42.4 40 2.4
Western Europe	1.72	0.7	48.2
Eastern Europe	0.89	0.25	8.9
Latin America	0.11	0.15	0.7
Africa/Mid-East	0.15	0.07	0.4
Asia	0.53	0.10	2.1
Oceania	0.05	0.7	1.5
<u>WORLD</u>			<u>104.2</u>

and other private enterprises.

The world's crops, counting species, subspecies and varieties, number several hundred different commercial products. Most important in terms of market value, quantity and caloric content are the staple crops, shown in Figures 4, 5 and 6. Note that Figure 4 does not reflect the significant increase in prices which occurred during 1973; at 1973 prices, the values shown would approximately triple.

We see from these figures that grain crops are the most significant: they account for approximately three-quarters of the food consumed by man. In certain countries, productions such as coffee, bananas, or cocoa represent the most significant agricultural product: the approach illustrated following for the grains applies, *mutatis mutandis*, to these crops as well. The Hayami-Peterson theory, although greatly simplified, indicates a significant world benefit accruing to increased crop forecasting accuracy.

## 2.2 Current Methods of Crop Forecasting

The first step in the methodology of application of Remote Sensing is the thorough understanding of how the production of grain crops is forecasted by current methods. The most sophisticated forecast system, is exemplified by the United States Department of Agriculture (USDA)'s Statistical Reporting Service (SRS). Since much information is available on this system, we can conveniently use it as an example.

The key elements of the SRS information gathering and dissemination cycle are shown schematically in Figure 7.

Shown in Figure 8 are SRS's three principal sources of data: a) voluntary reports from individual farmers (9.5 million questionnaires mailed

# TOTAL WORLD STAPLE CROP VALUE (1972) AT EXPORT PRICES

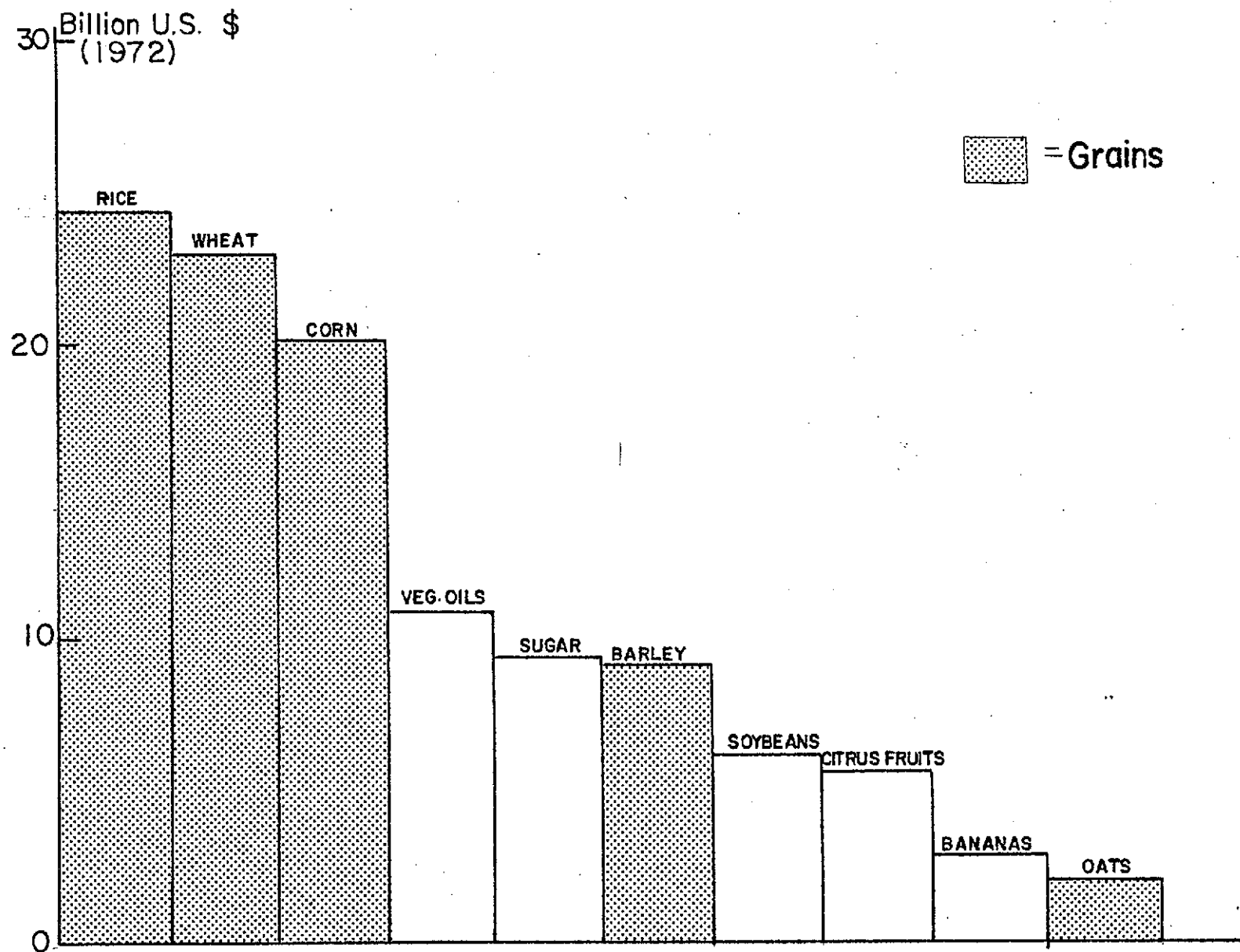


FIGURE 4

# WORLD STAPLE CROP PRODUCTION

(1972)

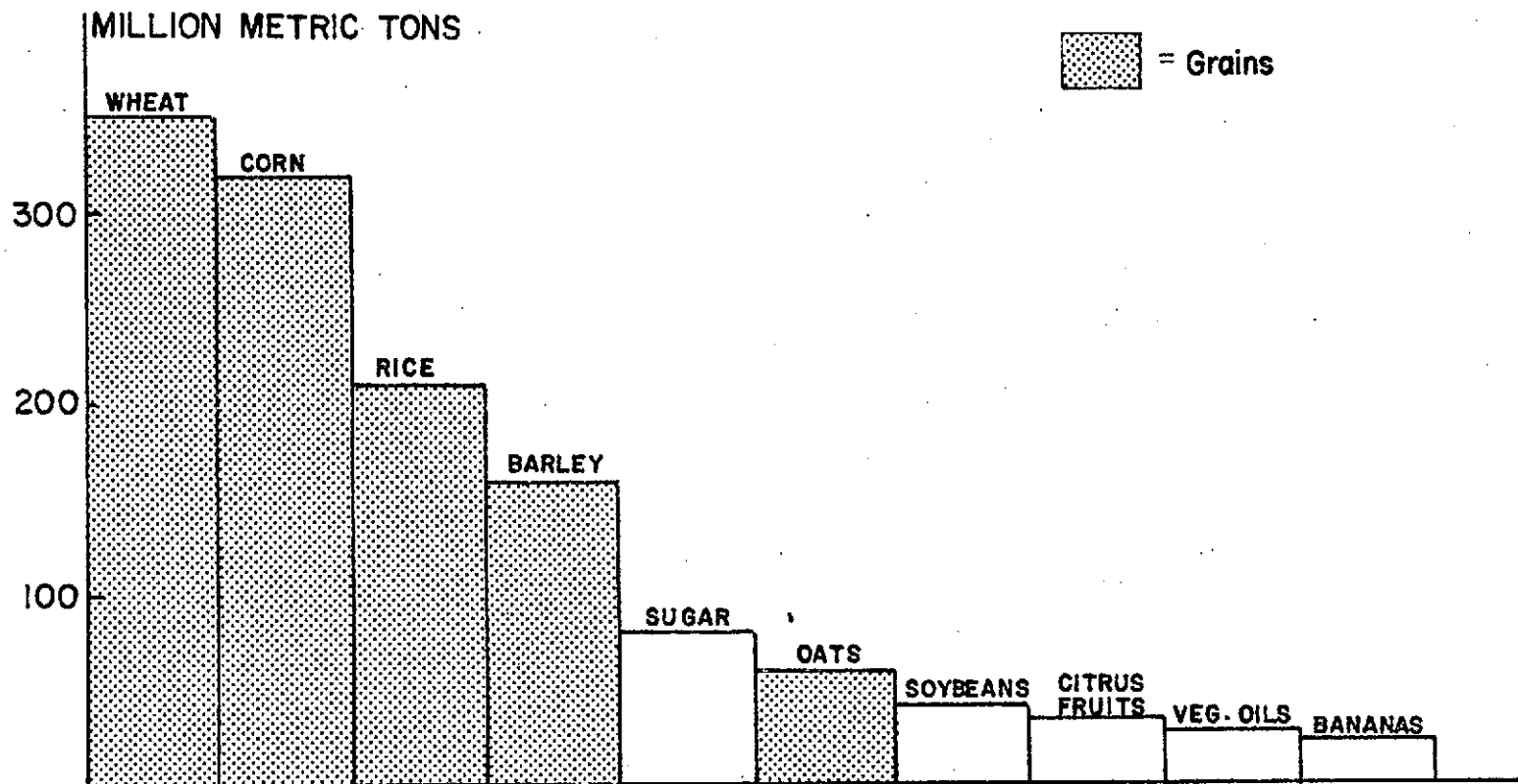


FIGURE 5

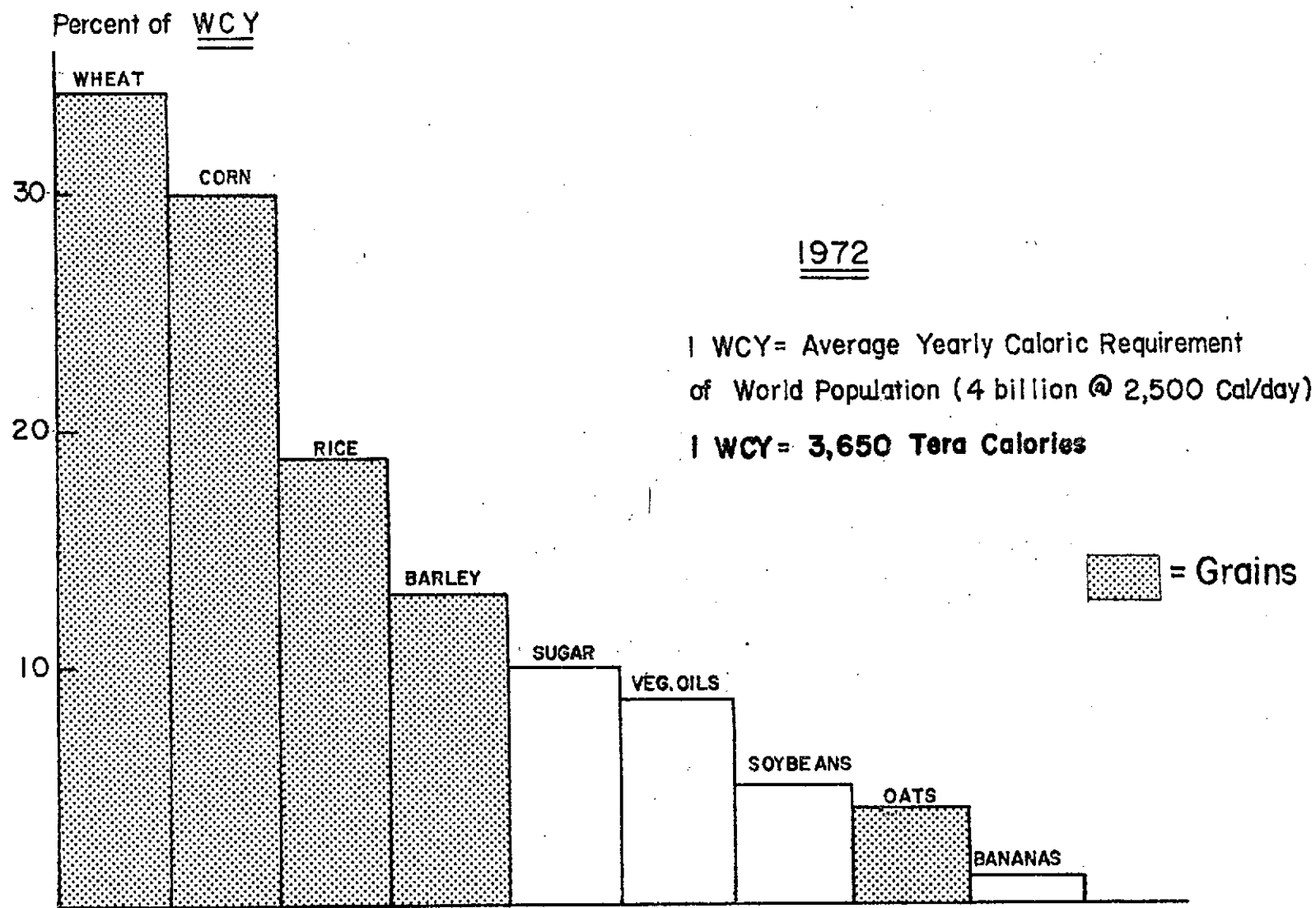


FIGURE 6 CALORIC CONTENT OF WORLD STAPLE CROPS

Reports :

Crop March  
Production  
PROSPECTIVE  
PLANTINGS

Wheat May  
Situation

HIGHLIGHTS  
OF U.S CROP  
REPORT AS  
OF AUG

Crop  
Production  
Annual  
Summary  
Acreage Yield

Agriculture  
Statistics  
19

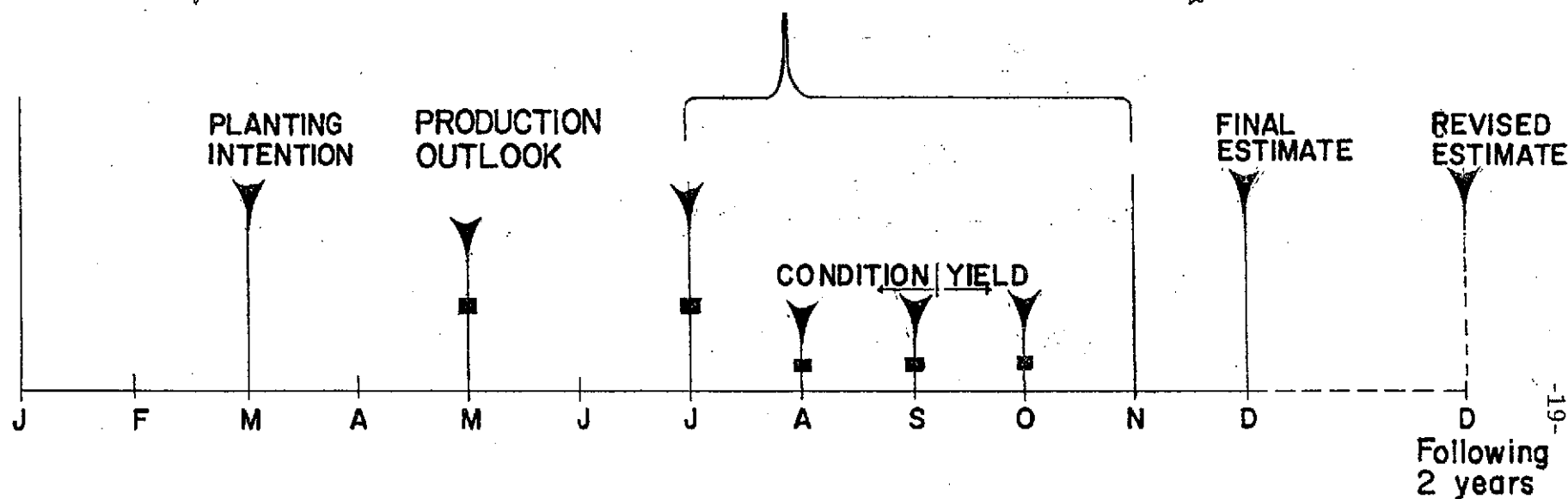


FIGURE 7 TYPICAL USDA (CORN, WHEAT) FORECAST AND FORECAST RELEASE CYCLE

▽ = Reports to Public  
■ = Forecasts

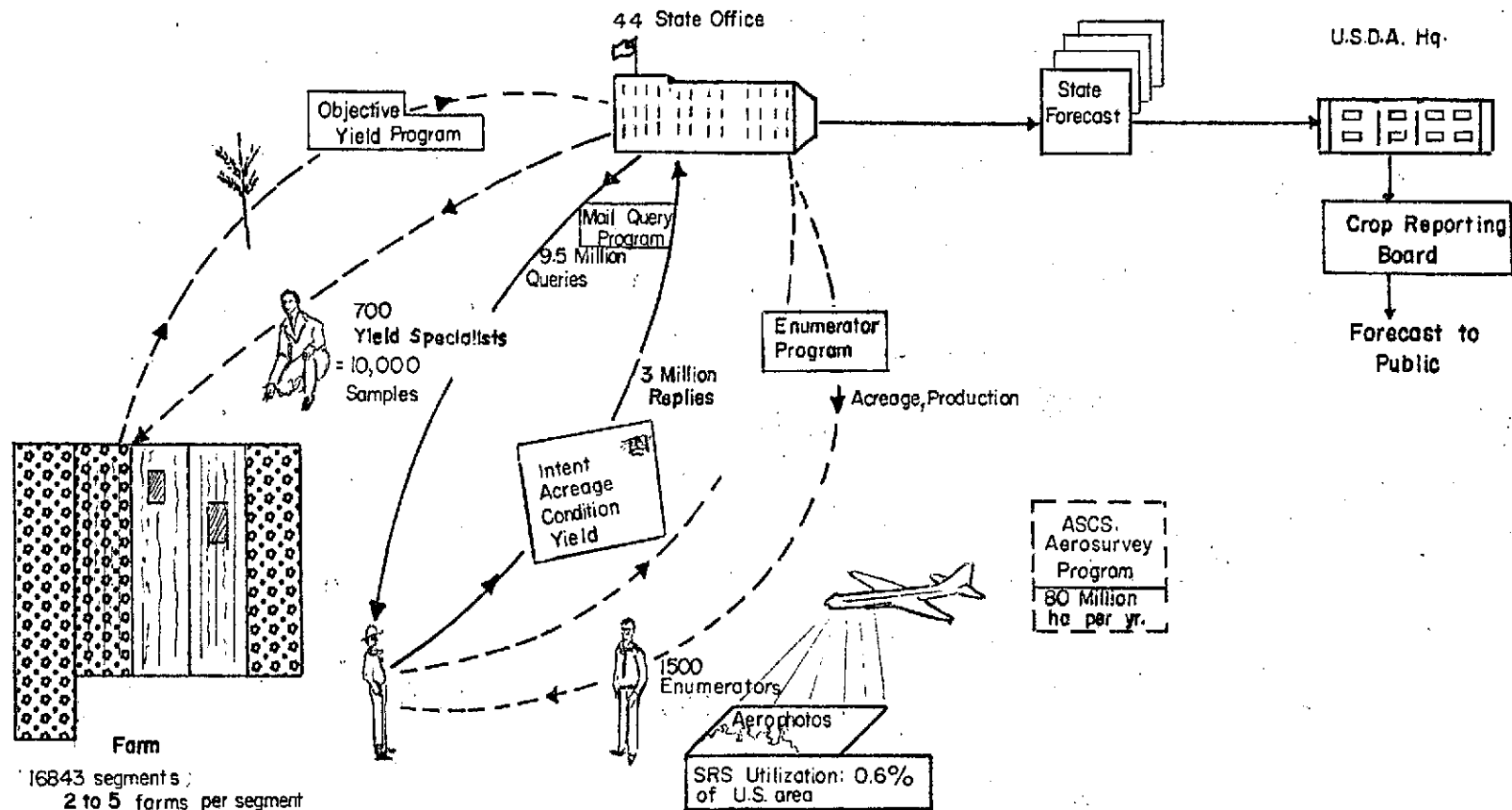


FIGURE 8 SIMPLIFIED USDA DATA GATHERING PROCEDURE

yearly, approximately 3 million responses); b) objective yield measurements by specialists; c) direct sampling of selected farms by specialists (enumerators), through farmer interviews supported by aerial survey information.

A typical reporting form periodically filled out by individual farmers is shown in Figure 9. Aerial photography at scale of order 1:20,000 is used by USDA's enumerators to precisely mensurate a limited number (approximately 0.6% of total farm area) of farm producing units. The farmer's information is validated by planimetering the farm's area, accurately identified on the photograph.

Yield prediction (bushels per acre or quintals per hectare) is performed by: a) the farmer, who assesses the "condition" of the crop (its status with respect to what it was at the same time last year); and b) specialized personnel who perform "objective measurements" of various indicators of plant development on selected test plots; e.g., plant density, number of ears, number of spikelets, and so forth.

These reports are integrated by the central Crop Reporting Board, which issues monthly forecasts beginning 4 to 6 months prior to harvest, depending upon the crop. A final estimate of production is given shortly after the harvest.

USDA corrects their estimates over the following two years, based on additional information which becomes available on the amounts of grain products actually processed and sold by food industries. As evidenced by Figure 10, the corrections are quite small. Compare these small fluctuations with the variances of selected other countries. At first blush, the fluctuations in typical developing Nations appear to reflect a considerably higher degree of uncertainty than exists in developed Nations.

JUNE 1974 ACREAGE SURVEY

CROP	ACRES FOR HARVEST	
	THIS YR.	LAST YR.
1. CORN		
2. WHEAT		
3. OATS		
4. BARLEY		
5. RYE		

PLEASE REPORT THE CONDITION AS COMPARED WITH THE NORMAL GROWTH AND VITALITY YOU WOULD EXPECT AT THIS TIME. LET 100 PERCENT REPRESENT A NORMAL CONDITION.

JULY 1

REPORT FOR YOUR FARM:

ACRES OF CORN HARVESTED LAST YR.  
----- ACRES

ACRES FOR HARVEST ----- ACRES  
THIS YEAR

REPORT FOR YOUR LOCALITY:

ACRES FOR HARVEST THIS YEAR  
COMPARED WITH ACRES HARVESTED  
LAST YEAR ----- %

CONDITION OF CORN ----- %

PROBABLE YIELD/ACRE ----- BU. -----

ANSWERS  
HERE



ADD ABOVE (INCLUDE -----  
ACRES OF ALL LAND IN THIS FARM  
(INCLUDE LAND RENTED) -----

NAME -----

ADDRESS -----

PLEASE ANSWER THESE QUESTIONS  
FOR THE FARM YOU OPERATE

ANSWER  
HERE



CROP PRODUCTION AND STOCKS

CORN PRODUCED ON THIS FARM LAST YEAR  
70 LB. EAR OR 56 LB. SHELLS BUSHELS

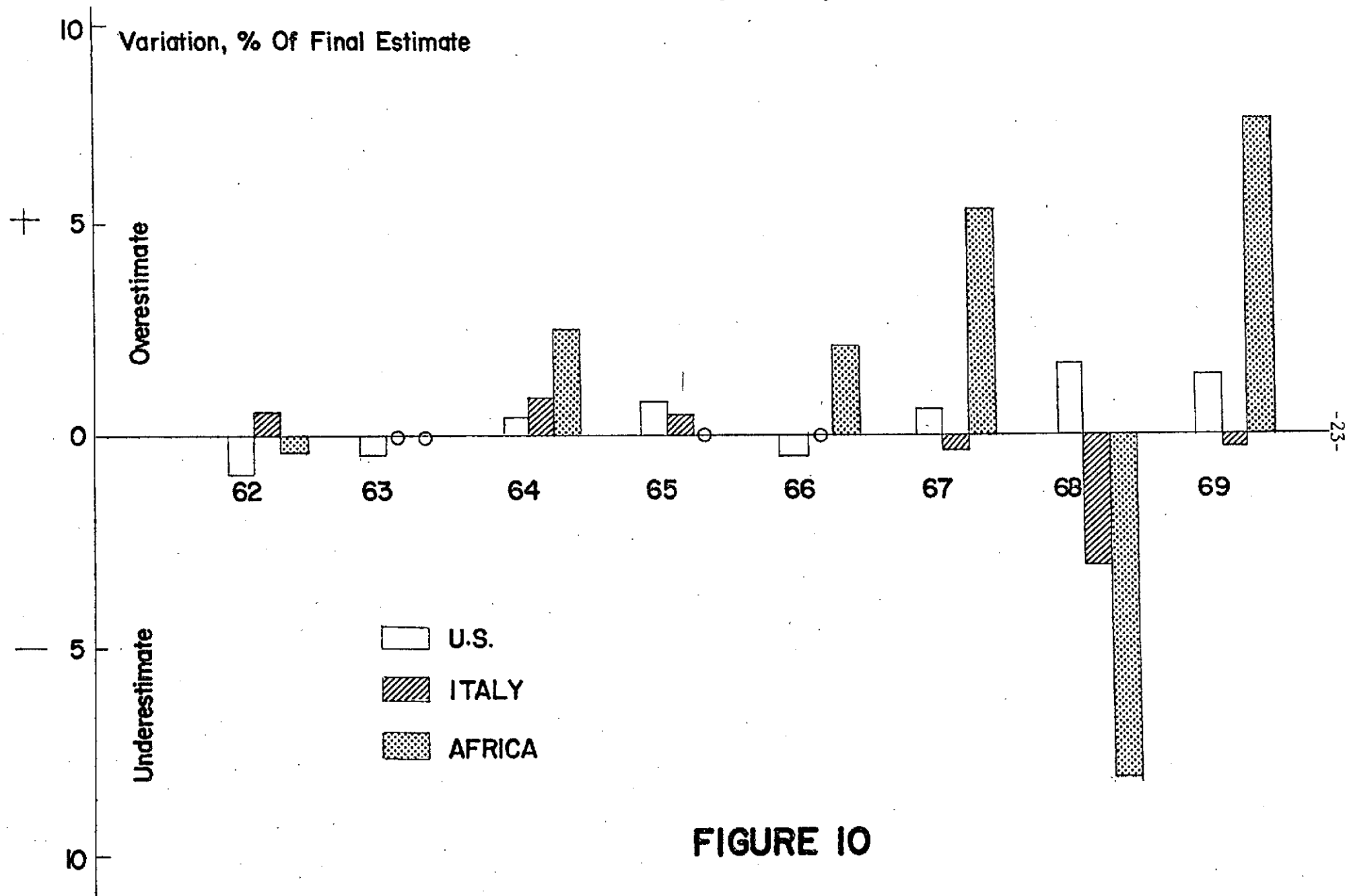
CORN ON THIS FARM JAN 1, 1974  
70 LB. EAR OR 56 LB. SHELLS BUSHELS

ALL WHEAT PRODUCED ON THIS FARM  
LAST YEAR - 60 LB. BUSHELS

ALL WHEAT ON THIS FARM JAN 1, 1974  
60 LB. BUSHELS

FIGURE 9 TYPICAL REPORT FORMATS,  
U.S. FARMERS

# VARIATION BETWEEN PRELIMINARY AND FINAL ESTIMATE OF WHEAT PRODUCTION (USDA)



USDA's method of forecasting production is based upon the product of two factors: 1) the acreage planted, and 2) the estimated yield (bushels per acre or quintals per hectare). The yield estimate is based upon a regression formula of the type:

$$Y = aX_1 + bX_2 + cX_3 + dX_4$$

Where:

$X_1$  is the "condition" of the crop at time of estimate, reported by the farmer or crop surveyor;

$X_2$  is the precipitation, in inches, which occurred during the previous two months;

$X_3$  is the precipitation, in inches, which is predicted will fall in the following two months;

$X_4$  is the time to go, in weeks, from the moment of estimate to final harvest;

a, b, c, d are coefficients whose value is derived from regressing historical records over approximately the previous fifteen years.

Implicit in this formula is the hypothesis that the methods of cultivation: a) fertilizer input, b) weeding effectiveness, c) density of planting, and so forth, are essentially constant from year to year, and will be practiced by the individual farmer with the same diligence and with the best technology known at present. Also implicit is the assumption of a "normal" year as regards crop disease. The occurrence of diseases such as wheat rust or corn blight, or unusual events such as floods, is factored in by the farmers and specialized survey personnel, who amend their estimate, upon detection, in the next monthly reporting period.

Note that in the formulation above, the only corrector of the estimates is precipitation: rainfall is assumed to be the principal driving function

for yield. While this assumption has been found adequate for the US, it may not be optimal for Nations subject to different climatologies. France, for example, is considering the use of the additional variable of integrated temperature (degree-days) for their yield model.

A measure of the accuracy of forecasts referenced to the "final" yearly estimate for the last several years is indicated in Figure 11. Figure 12 depicts the average historical trend of forecast accuracies, Figure 13 shows the average accuracy experienced over the last 15 years for winter wheat, the major variety of US wheat.

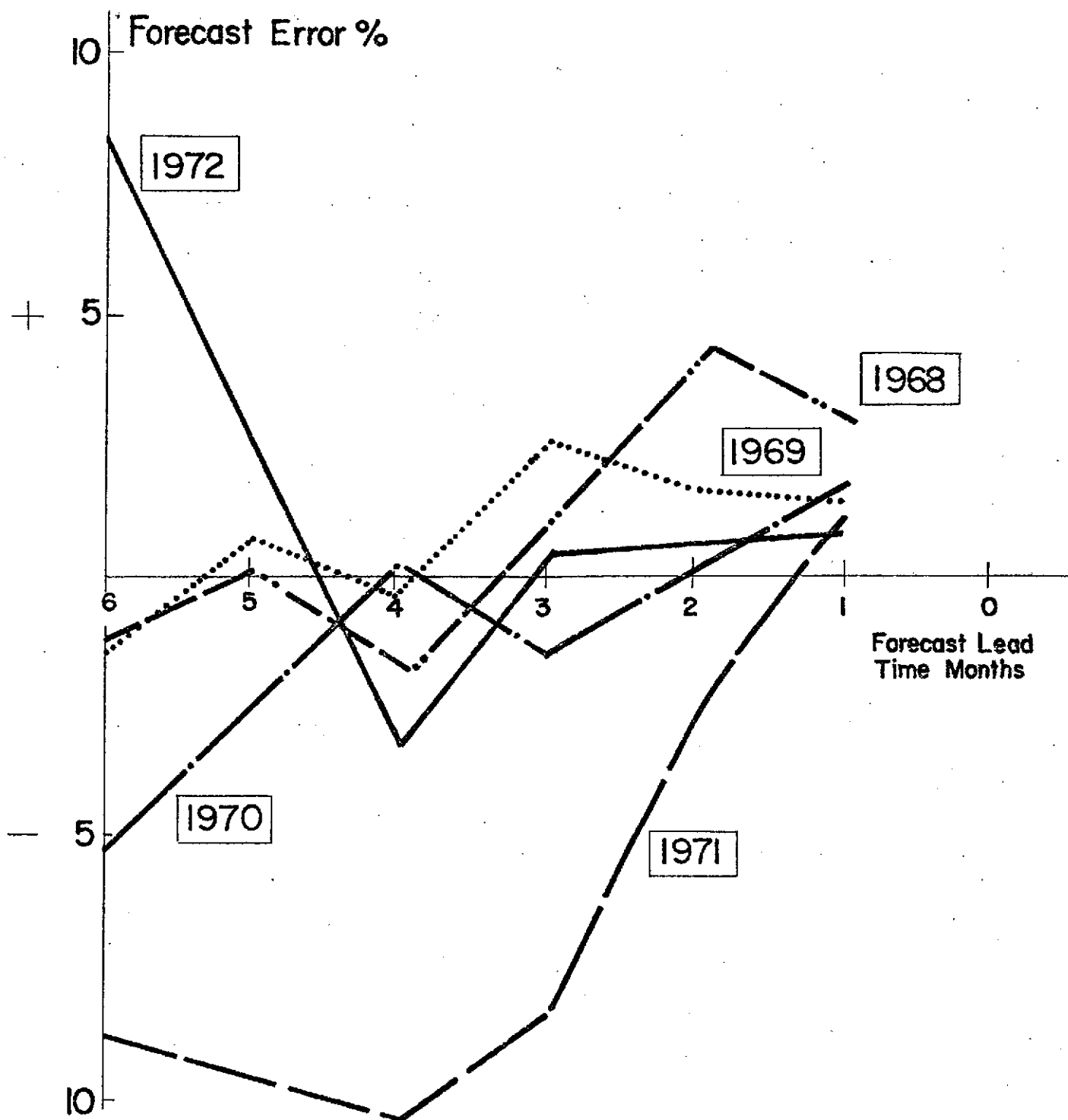
The relative contribution to the forecast of the acreage and yield components is shown in Figure 14, which compares the fluctuations in US wheat production with the variations in acreage and yield. Note that acreage fluctuations account for almost 50% of the total production variance.

The USDA system is substantially followed, with varying degrees of sophistication, by the developed Nations. In developing Nations, simpler systems are employed. Table 2, based upon FAO data, categorizes the crop reporting systems employed by the majority of the world's nations. Note that the complete system composed of farmer reports, plus objective yield measurement plus enumeration by specialists is used in general in those countries which possess the highest levels of living and literacy rate. As the GNP per capita diminishes, crop measurement systems tend to eliminate farmer reports and rely primarily upon sample measurements by specialists. The frequency and sophistication of the sample procedures also tend to decrease with decreasing GNP per capita. Table 3 synthesizes the world's current crop reporting systems into three fundamental categories: Developing, Intermediate, Advanced.

# FIGURE II

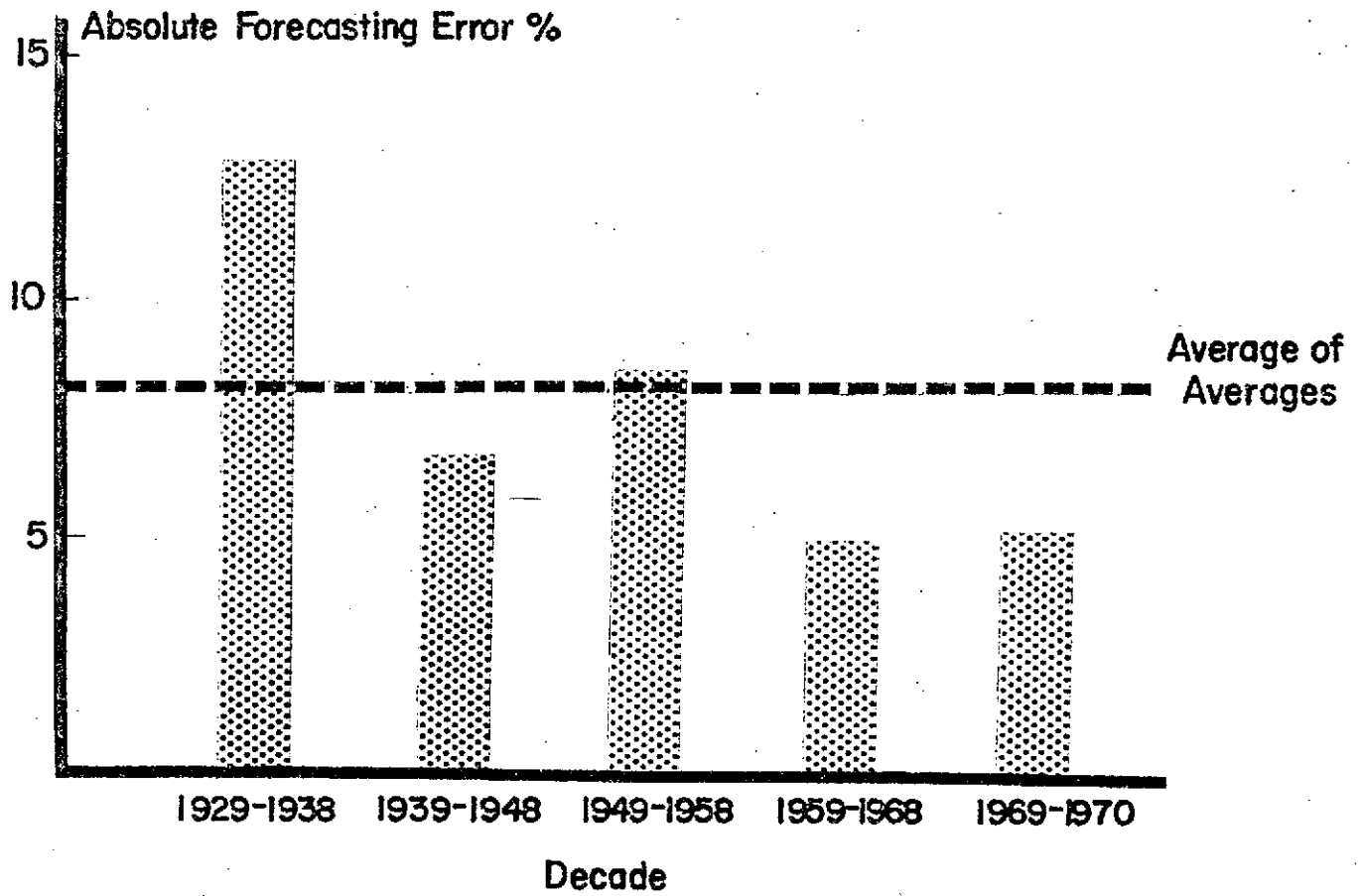
## PUBLISHED USDA-SRS FORECAST ACCURACY

### WINTER WHEAT - TOTAL U.S. CROP



**FIGURE 12**

**TREND OF AVERAGE USDA FORECASTING ERRORS**  
(major commodities)



USDA-SRS AVERAGE CROP FORECASTING ERROR  
VERSUS TIME PRIOR TO CROP YEAR CLOSE

(Winter Wheat)

Data cover years 1957-1972

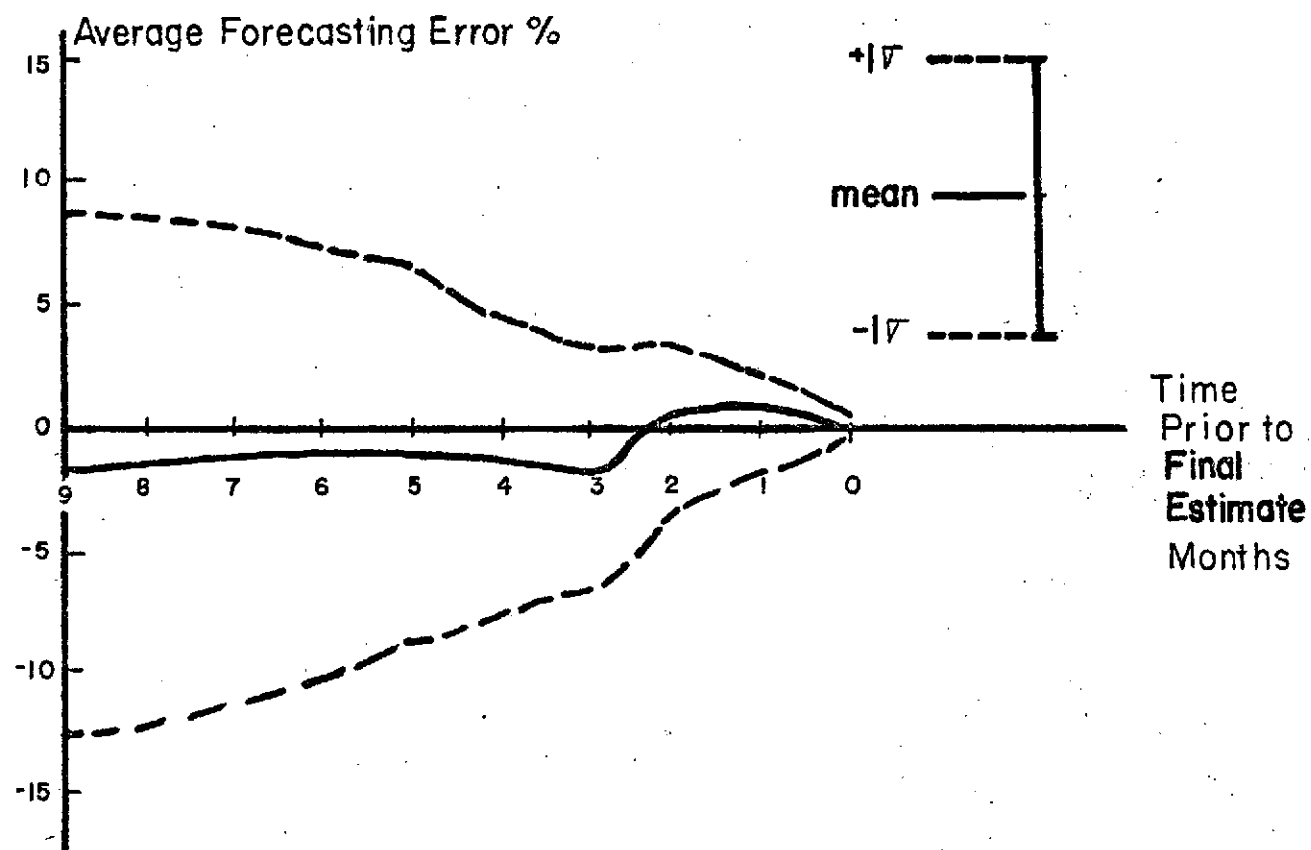
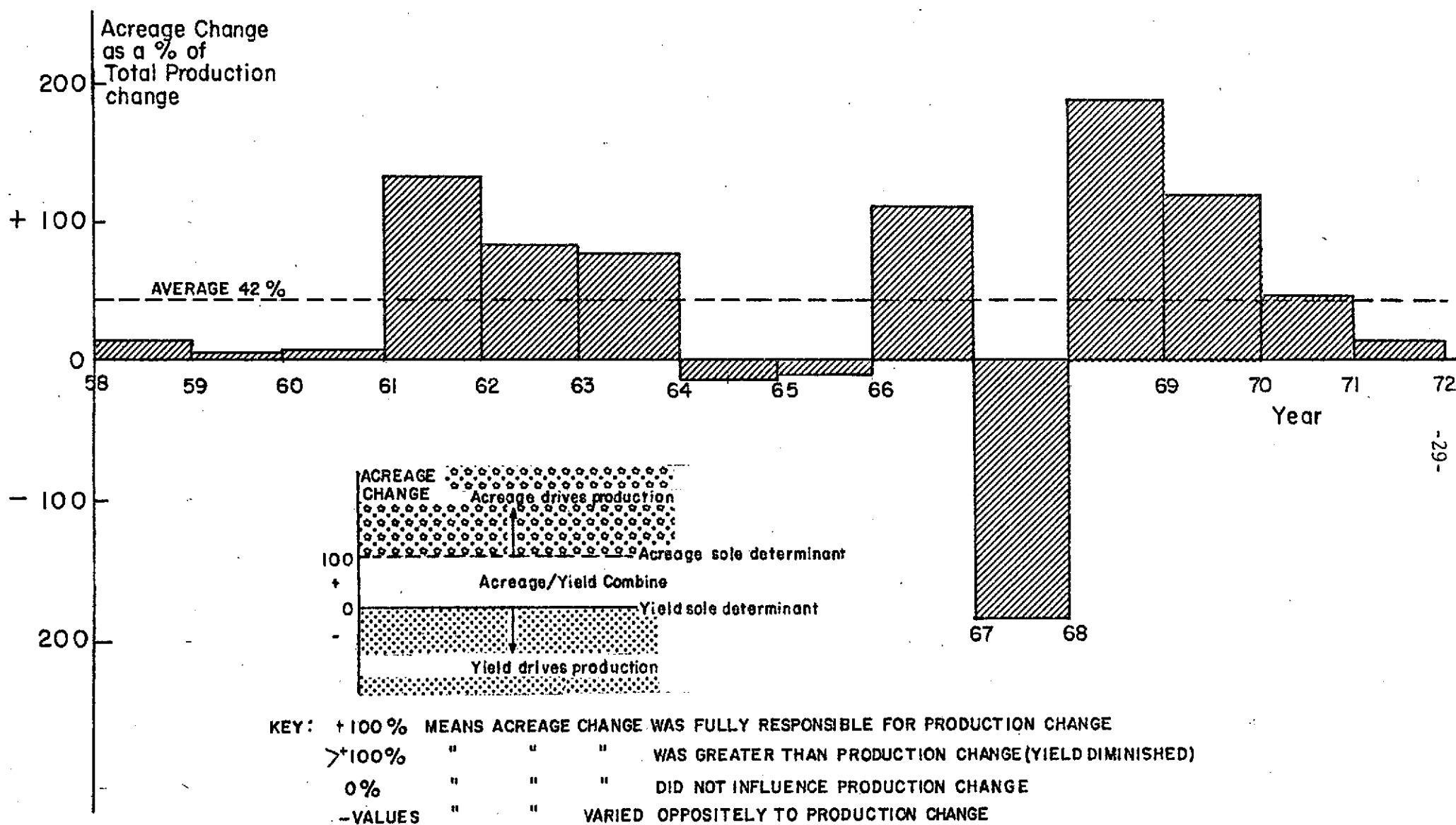


FIGURE 13

FIGURE 14 CONTRIBUTION OF ACREAGE HARVESTED TO TOTAL WHEAT PRODUCTION



# TABLE 2 COUNTRIES INVOLVED IN CROP SURVEY ANALYSIS

SURVEY CLASSIFICATION			
Country	Acreage Forecast	Yield Forecast	Statistical Sampling
<b>EUROPE</b>			
Austria	A	B	--
Belgium	A	B	--
Denmark	A	A	S
Finland	A	A	S
Germany FR.	A	B	S
France	A	D	--
Greece	B	B	--
Ireland	A	A	S
Italy	B	B	S
Luxembourg	A	B	--
Netherlands	A	B	S
Norway	A	B	S
Portugal	C	C	--
Spain	A	B	--
Sweden	A	B	S
Switzerland	A	B	--
United Kingdom	A	C	S
Yugoslavia	B	B	S
<b>NORTH-CENTRAL AMERICA</b>			
Canada	A	A	S
Costa Rica	A	A*	S
Dominican Republic	A	A	--
El Salvador	B	B	--

SURVEY CLASSIFICATION			
Country	Acreage Forecast	Yield Forecast	Statistical Sampling
Guadalupe	B	B	--
Guatemala	A	A*	--
Martinique	B	B	--
Mexico	B	B	--
Panama	A	A*	S
Puerto Rico	A	A*	S
USA	A	A	S
<b>SOUTH AMERICA</b>			
Argentina	A	A	S
Brazil	C	C	S*
Chile	A	D	--
Colombia	A	A*	S*
Ecuador	A	A*	--
Fr. Guiana	--	--	--
Paraguay	A	C	S*
Peru	D	D	--
Surinam	A	A*	--
Uruguay	A	A*	S
Venezuela	B	B	--
<b>ASIA</b>			
Burma	A	A	--
Ceylon	A	B	S
Cyprus	A	A*	--

SURVEY CLASSIFICATION			
Country	Acreage Forecast	Yield Forecast	Statistical Sampling
Malaya	A	A*	S
India	A	B	--
Indonesia	B	A	--
Iran	D	D	--
Iraq	C	C	--
Israel	B	B	S*
Japan	A	B	S
Jordan	C	C	--
Lebanon	C	C	--
Pakistan	C	C	--
Philippines	B	B	--
Syria	C	C	--
Thailand	B	B	--
Turkey	B	B	S
<b>AFRICA</b>			
Algeria	B	B	--
Sudan	B	B	--
Basutoland	D	D	S
Bechuanaland	C	C	--
Belgian Congo	B	B	--
Egypt	A	A*	--
Cameroons, Fr.	A	A*	--
Morocco, Fr.	C	C	--

SURVEY CLASSIFICATION			
Country	Acreage Forecast	Yield Forecast	Statistical Sampling
Somaliland	D	D	--
Togo	A	A*	--
Fr. West Africa	A	A*	--
Gold Coast	A	A*	S*
Kenya	A	A	--
Madagascar	C	C	--
Nigeria	D	D	S*
Rhodesia, Northern	A	A	--
Nyasaland	A	A	--
Rhodesia, So.	A	C	--
Morocco, Sp.	A	A*	--
Swaziland	A	A*	--
Tanzania	D	D	S*
Tunisia	A	A*	--
Union South Africa	A	A	--
Uganda	C	C	S*
<b>OCEANIA</b>			
Australia	A	A	S*
Fiji	A	A	--
Hawaii	A	A	--
New Caledonia	A	A*	--
New Zealand	A	A	S

Explanation of Symbols: [A] Sampling at farm level [B] Sampling at commune level [C] Sampling at district level [D] Sampling at province level [S] Stratified Sampling  
\* System under development

TABLE 3 THE THREE BASIC LEVELS OF CROP FORECASTING SYSTEMS			
	<u>Developing</u>	<u>Intermediate</u>	<u>Advanced</u>
	Typical: Dominican Republic	Typical: Italy	Typical: United States of America
Regional Administrative Structure	1599 sections grouped into 69 communes	7851 Communes grouped into 91 Provinces	1700 enumerated areas grouped into 44 States
Crops Surveyed	Maize, rice, beans, potatoes, onions, garlic, peanuts, coconuts, oranges, bananas, cocoa, sugar cane, plantains, pineapple, coffee (in pod), avocado, pears, cotton, tobacco	Wheat, rye, barley, oats, maize, rice, sugar beets, potatoes, peas, beans, vineyards, fruits, olives, linseed rapeseed, vegetables, tobacco, fibers	Grains, fodder crops, tuber and root crops, sugar crops, pulses, oilseeds, hay and grass seeds, vegetable seeds, fruits, nuts, vegetables, tobacco, fibers
Methods of Data Gathering	<ul style="list-style-type: none"> <li>• Interview of producers by enumerators</li> </ul>	<ul style="list-style-type: none"> <li>• Crop area from personal judgement, supplemented by cadastral survey</li> <li>• Crop yields from local inquiry</li> </ul>	<ul style="list-style-type: none"> <li>• Direct inquiry to farmer respondents</li> <li>• Enumerators with aerial photos</li> <li>• Objective yield measurement by specialists</li> </ul>
Sampling Structure	None	Simple sampling procedure	Multi-frame stratified sampling procedures
Organization	Municipal Statistical Board in each commune	<ul style="list-style-type: none"> <li>• Data from commune collected by local correspondent assisted by provincial agricultural inspector</li> <li>• Central Institute of Statistics issues technical directives and publishes results</li> </ul>	<ul style="list-style-type: none"> <li>• SRS HQ staff supported by 44 State offices comprising 9 crop regions.</li> <li>• Refer to Figure 9</li> </ul>
Frequency of Crop Reporting	Every 3 months	Two crop reports per year First estimate at planting time; second estimate at harvest	Multiple crop reports per year. Intentions to plant-yearly per crop. Acreage, crop condition, production forecast - monthly for 3-6 months. Final production and yield-yearly.

The fundamental basis for potential improvements in accuracy rests upon the fact that present methods, for budgetary reasons, only measure limited samples of acreage and/or yield. The sample, no matter how carefully taken, does not represent the full reality of the situation. In extrapolating the sample onto the entire national production, errors are committed whose magnitude is roughly proportional to the departure between the situation indicated by the sample and the overall situation. For example, Figure 15 depicts USDA's estimate of the accuracy of acreage measurement corresponding to increased sampling.

As regards yield estimates, the benefits of increased sampling still applies but with significant differences. Expected yield is based to a significant degree upon the assessment of present crop condition. To the extent that this quantity can be measured more accurately by increasing the number of samples, yield forecasts will be improved. However, yield also depends upon other factors more difficult to estimate: principal among these is weather. Therefore, until the state of technology will allow accurate prediction of weather, an irreducible uncertainty will remain in the forecast. Better sampling methods can, however, materially assist in reducing the errors to the minimum possible.

### 2.3 State of the Art of Remotely Sensed measurement of Acreage

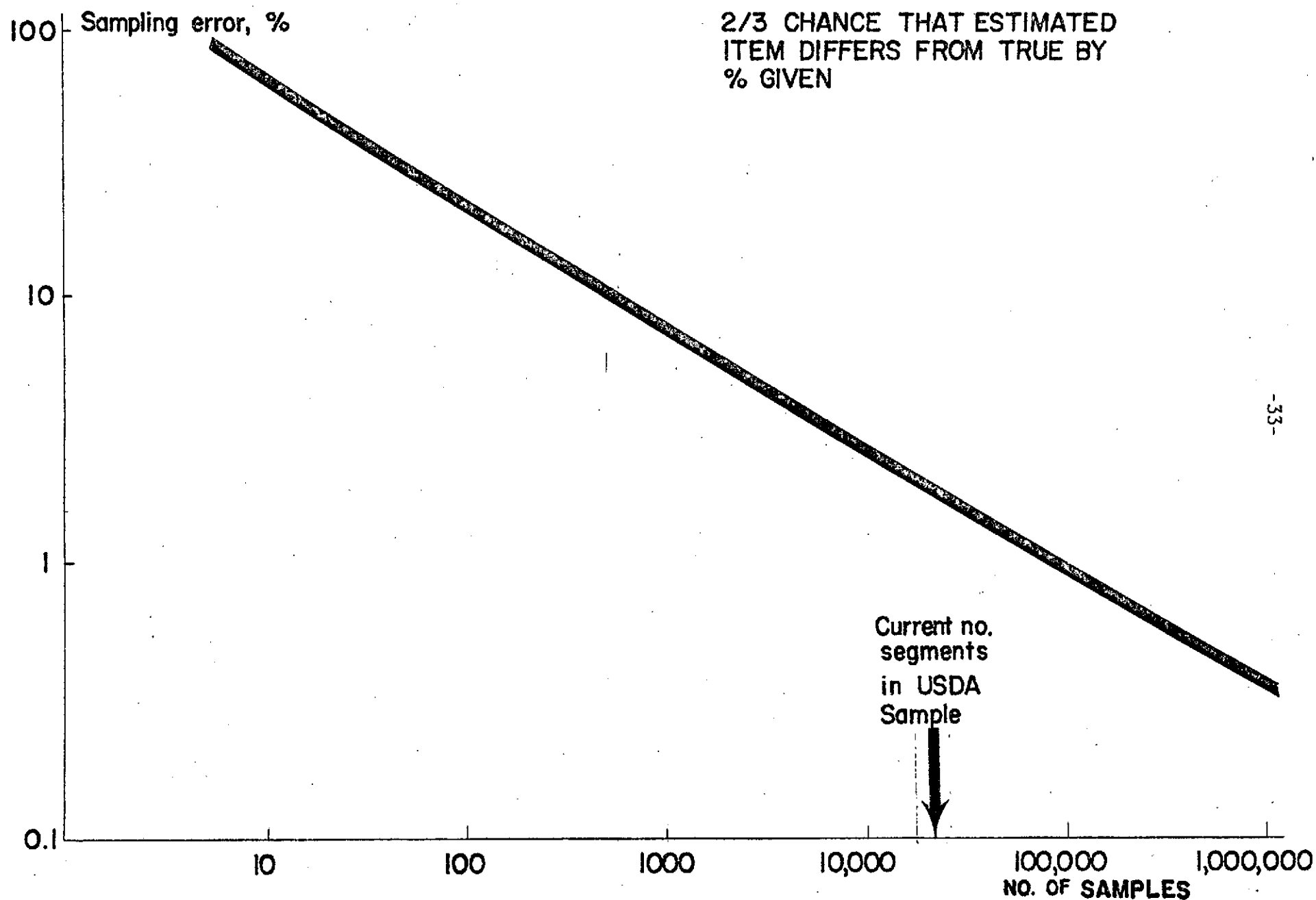
Measurement of crop acreage by remote sensing requires two capabilities:

1. Identification of crops, i.e. determination of which fields are planted with which crop;
2. Computation of the area of the fields carrying each crop.

#### 2.3.1 Identification of crops

This function is currently performed operationally by ground-based

FIGURE 15  
PUBLISHED SAMPLING RELIABILITY OF U.S.D.A. ACREAGE ESTIMATES



means. Results indicate that it can be successfully and immediately adapted to remote sensing.

The oldest method employs large scale imagery, order of 1:3000 to 1:5000, preferably in color, taken at favorable illumination conditions from altitudes of order 700 to 1000 meters, and interpreted by a human operator. This type imagery is, at the present state of the art, obtainable only from aircraft. The photointerpreter must be familiar with the crops of the area he is interpreting. The reason is that recognition by humans depends upon differences in color, texture, field shape, and other elements which vary with local season, local weather conditions, and differ, sometimes significantly, between regions. No "universal" processing algorithm exists which can unequivocally recognize for example wheat anywhere in the world. This will undoubtedly be developed in the future: at the moment, however, it is necessary to "regionalize" agricultural measurements to achieve accuracy. Experience in how local crops "look like" is therefore of great importance. The differentiation among crops and between crops and non-cultural vegetation varies with the type of vegetation. Table 4 indicates the accuracy with which different crops and vegetative covers have been differentiated by visual means on small scale imagery. A typical example of a logic chain for the visual identification procedure is shown in Figure 16. A corresponding aerial image is shown in Figure 17.

Differentiation between small grains as a whole (which include wheat, rye, barley) and other crops is quite good. Differentiation between different types of small grains for example: wheat from barley), is somewhat less precise. This is because these crops look alike when observed from above. Improved discrimination between small grain crops can be achieved by "catching" them on the imagery when they reach different stages of growth, which normally occur at different times: the differences become more clearly visible.

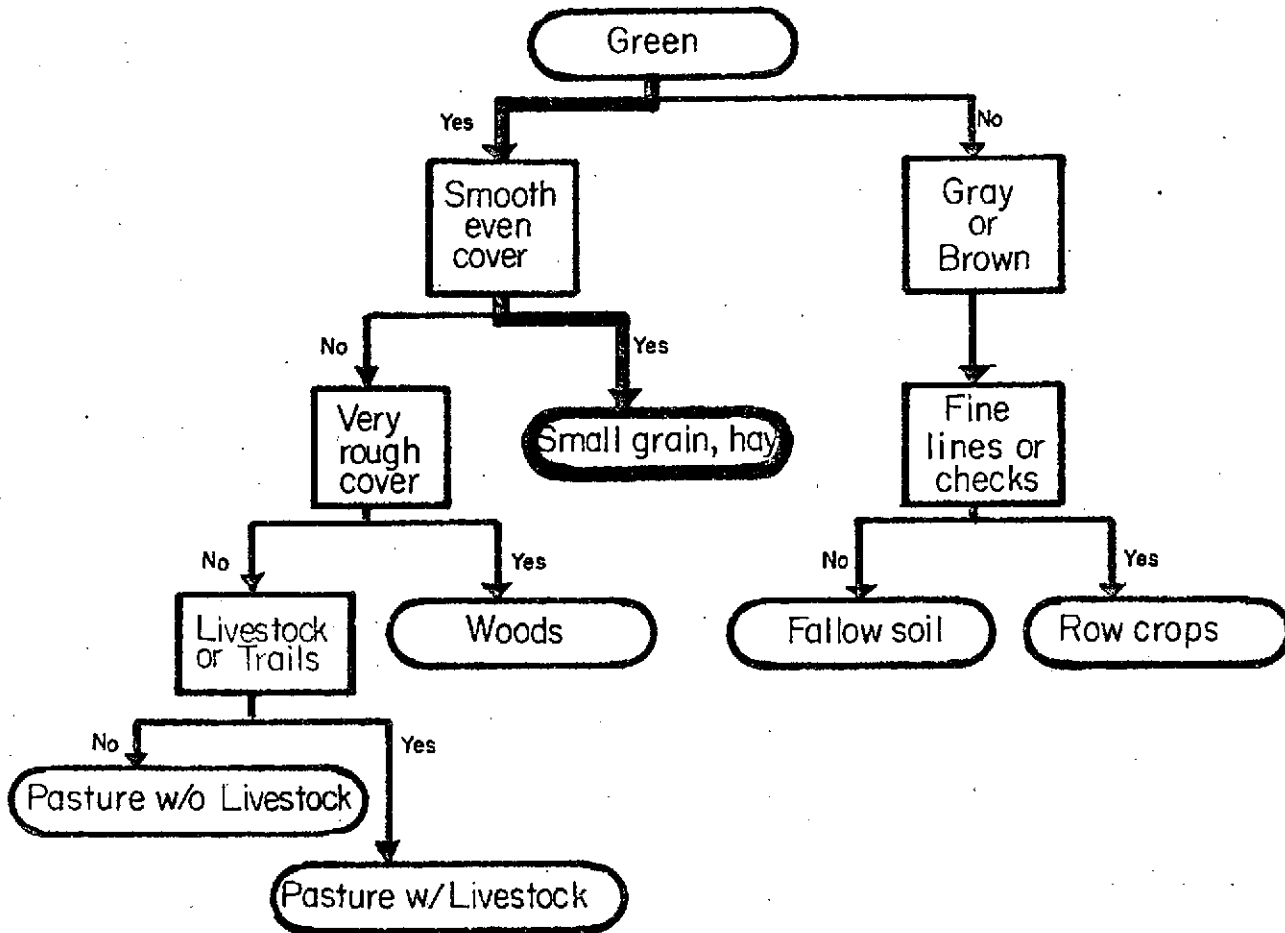
TABLE 4

ACCURACY OF REMOTELY SENSED CROP DISCRIMINATION

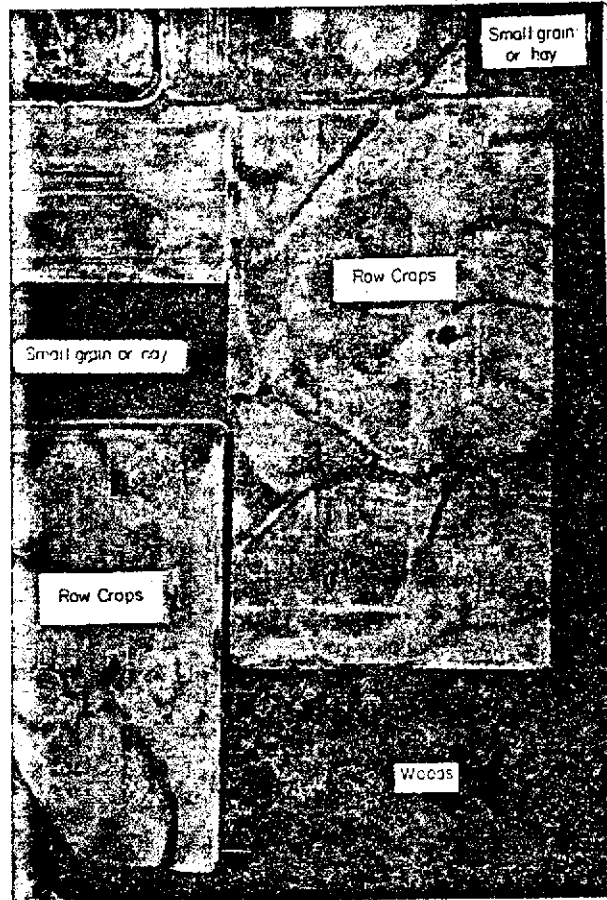
CROP	%Correct Identification	
	AIRCRAFT (Scale 1:40000)	SATELLITE (ERTS)
Small grains	100	---
Row crops	96	96
Pasture	96	84
Trees	100	86
Wheat	95	93
Oats	95	85
Water	100	100

--- = not available

Region: Ohio



**FIGURE 16 LOGIC CHAIN FOR IDENTIFICATION OF AGRICULTURAL CROPS AND PRODUCTS**



**Aerial Photography**

**Scale: 1:4000**

**Region: Ohio**

**FIGURE 17 EXAMPLE OF CROP  
DIFFERENTIATION  
BY REMOTE SENSING**

Recognition from aircraft requires frequent overflights: from satellites, these are available routinely. Recognition between similar crops can be improved by exploiting pre-knowledge of the region. If, for example, the region under consideration primarily produces wheat, the problem of differentiating between wheat and other small grains diminishes in importance.

Satellite imagery, currently produced at scales of order 1:1,000,000 to 1:250,000, provides less detail than is possible from low-flying aircraft imagery. This is offset by the increased sophistication of the sensory equipment and data processing techniques. Typical recognition accuracies achieved so far on individual samples are indicated in Table 4.

At first blush, the recognition accuracies quoted in Table 4 might appear marginal with respect to those achievable by ground-based methods. Note however that these accuracies apply to comparisons between selected samples - e.g., between limited numbers of wheat and soybean fields. Practical crop inventory and forecast systems are not concerned with estimating the size of individual fields, but rather the total acreage of a crop in a region. As we shall see in the next section, the recognition errors, when large areas are involved, tend to "wash out", resulting generally in total acreage estimates which are much better than what Table 4 would lead one to surmise. This is particularly so if sensor data processing procedures are used which take into account specific a priori information, such as: the shape and size of the fields characteristic of the region; the patterns of crops of the region; the prevalent neighborhood of certain crops to others; and so forth.

### 2.3.2 Computation of crop field area

Mensuration accuracy is affected by two primary factors:

The distortion of linear dimensions within the imagery;

The error caused by the resolution of the imagery;

Aircraft imagery is subject to systematic scale errors, which increase as the distance (obliquity) from the sub-aircraft point increases. The reason for, and magnitude of such errors for typical imagery are illustrated in Figure 18. Errors are corrected either manually, by scaling the dimensions measured on the imagery as a function of their distance from the nadir: or automatically, by an image-processing procedure known as rectification. For satellites such as ERTS, the errors are already very small. In addition, if needed, ERTS pictorial data can be procured already rectified, at nominal cost.

Resolution error is caused by the fact that the imagery is not infinitely sharp. This leads to some uncertainty in recognizing when one field ends and the other begins. The error in estimating the area of a field induced by this cause is given approximately by the empirical relationship, valid for A greater than 4 hectares:

$$e = \frac{100 \ r \ k}{\sqrt{A}}$$

Where:

e = percent error in area measurement

r = resolution of the system (for ERTS, approximately 70 meters)

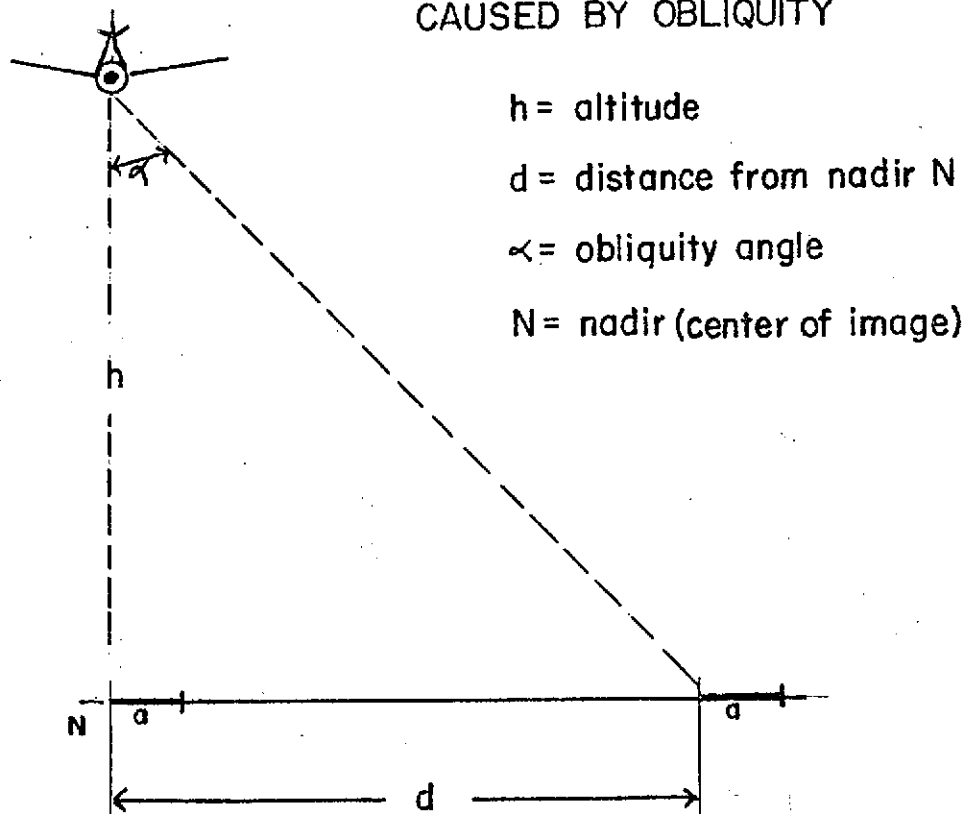
A = Area of field in square meters

k = resolution - improvement factor

k is a measure of the sophistication of the processing technique. It varies approximately from 1 (unsophisticated) to 0.25 (sophisticated processing).

Figure 19 depicts theoretical errors in mensuration of a single field

FIGURE 18. SCALE SHRINKAGE  
CAUSED BY OBLIQUITY



The same segment of length a will appear shrunk the further its distance from the nadir N.

The Apparent shrinkage will be:

$$\epsilon \% = \left( 1 - \frac{h}{\sqrt{h^2 + d^2}} \right) \times 100$$

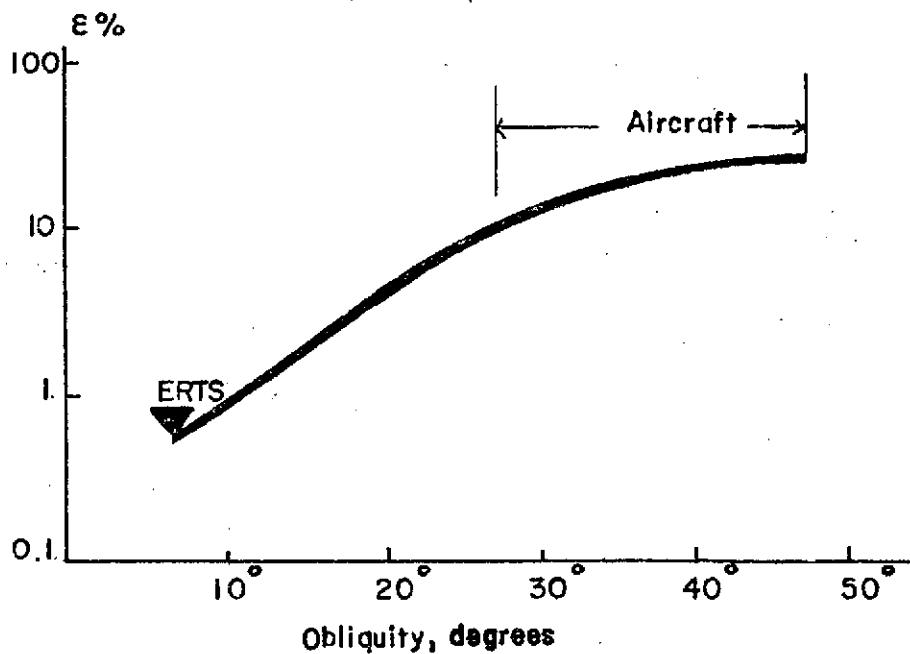
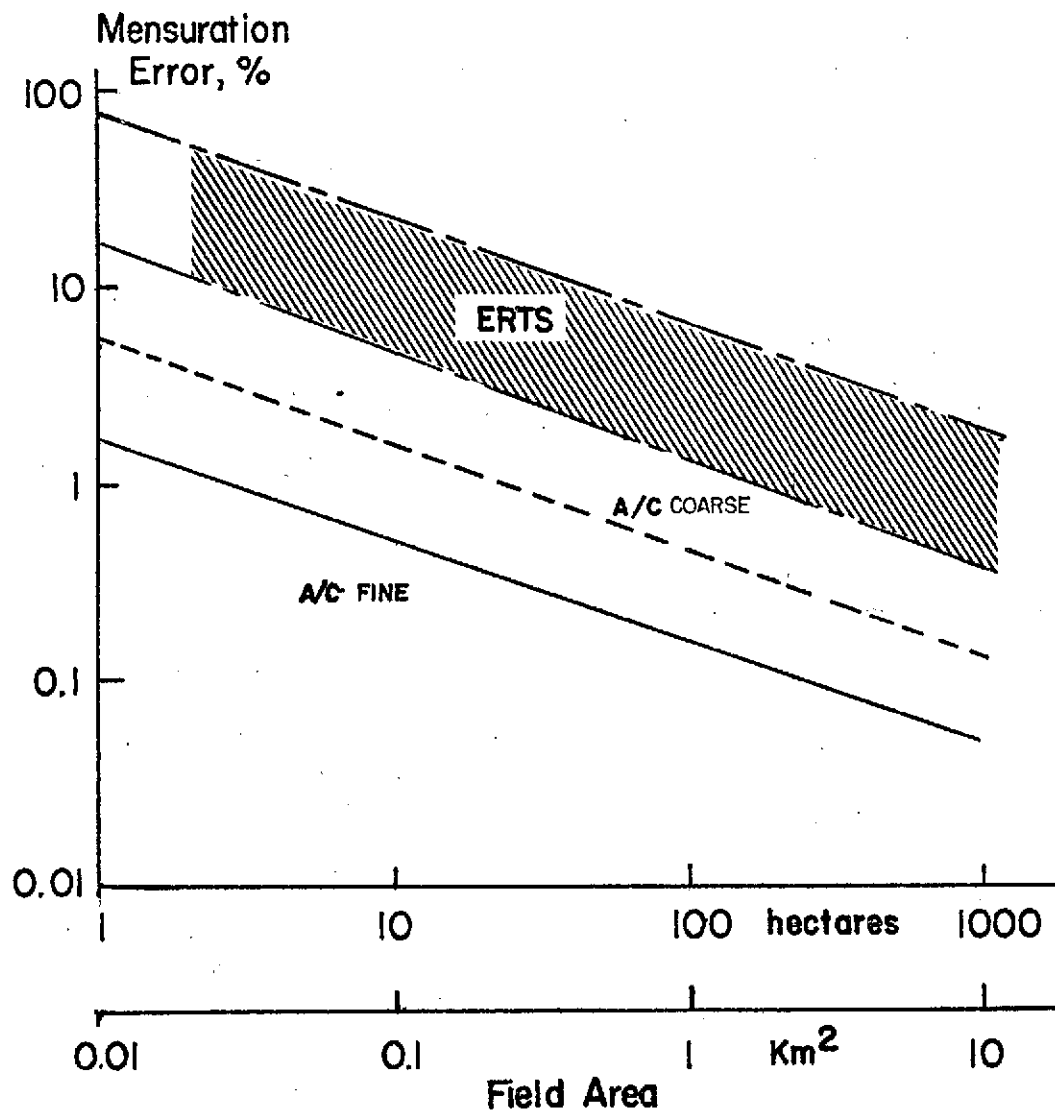


FIGURE 19 TYPICAL RESOLUTION -  
-INDUCED MENSURATION ERRORS, SINGLE FIELD



**Typical Resolutions:**

Aircraft coarse	:	5 meters
" medium	:	2 meters
ERTS	:	70meters

with satellite (ERTS) and aircraft imagery. The percentage error diminishes with increasing size of field. If several fields are sampled, the errors tend to add randomly, sometimes the estimate being too high, sometimes too low. The resulting error in estimating, for example, the area of  $n$  fields of the same size is approximately:

$$e_n = \frac{100 r \cdot k}{\sqrt{n} A}$$

Where:

$e_n$  = percent error in estimating total area of  $n$  fields

$r$  = resolution

$A$  = area of individual field

$k$  = resolution improvement factor

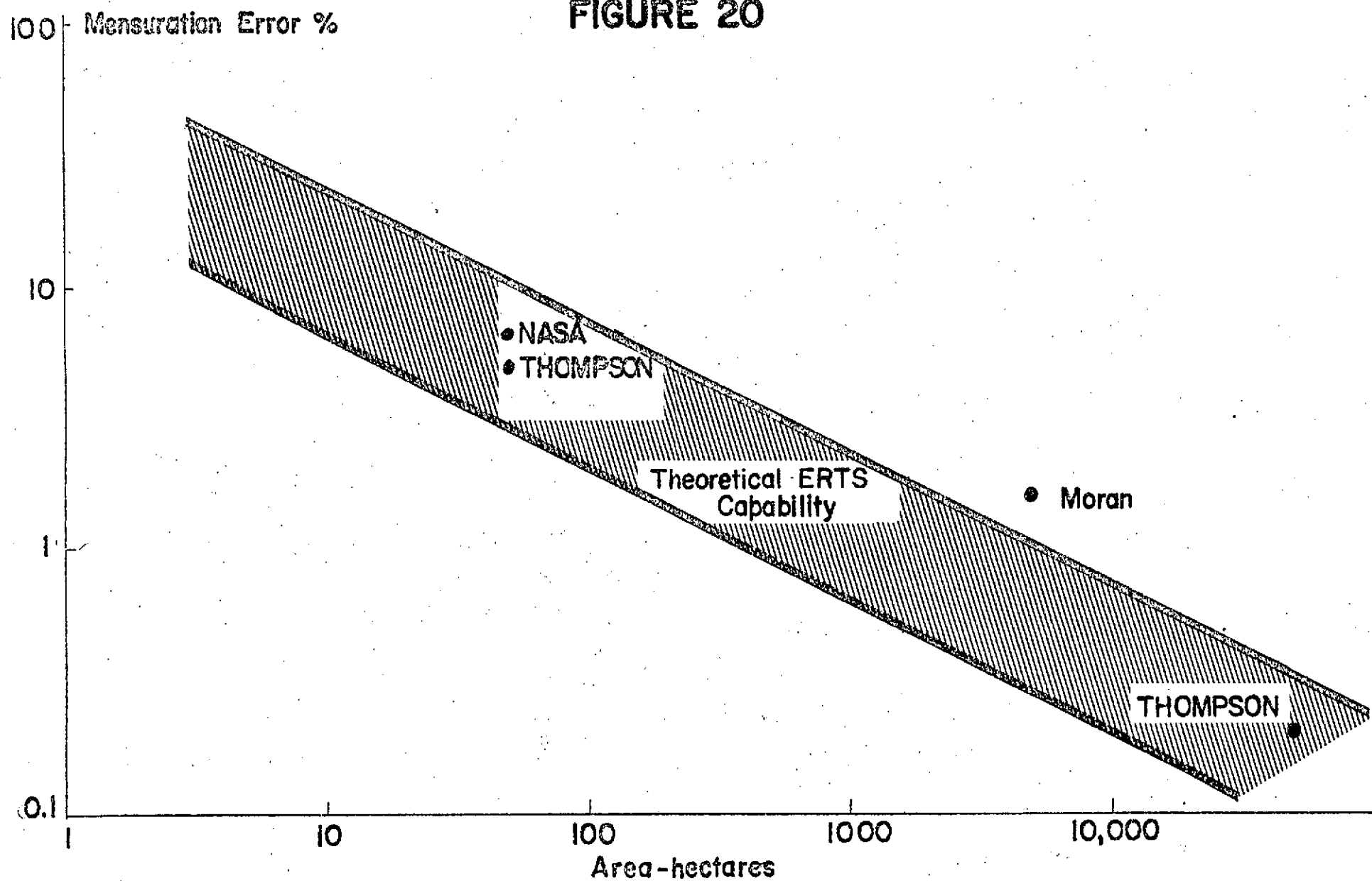
Similar expressions prevail if the fields are not all equal in size.

The measurement of crop acreage from remotely sensed information is thus subject to two errors: errors in recognition of the crop, and error in area mensuration. Results of actual mensuration of crop acreage by various ERTS-A investigators, which include both type errors, are indicated in Figure 20. Note that, for large areas and the appropriate crops, these errors can be lower than 1%. They will further diminish as development of processing techniques progresses. The computation of acreage can be performed manually or automatically.

The manual method involves planimetric measurement directly on the imagery, or by use of simple instruments such as optical viewers employing cursors which slide across the imagery entraining graduated distance-measuring scales and planimeter apparatus. The operator traces the border of the fields, reads and records the measurements. Instruments of this type cost approximately \$3,000. Motor-driven versions, equipped with automatic recording of the measurements, cost upward of \$75,000.

# COMPARISON OF ERTS RESULTS TO THEORETICAL MENSURATION ERROR

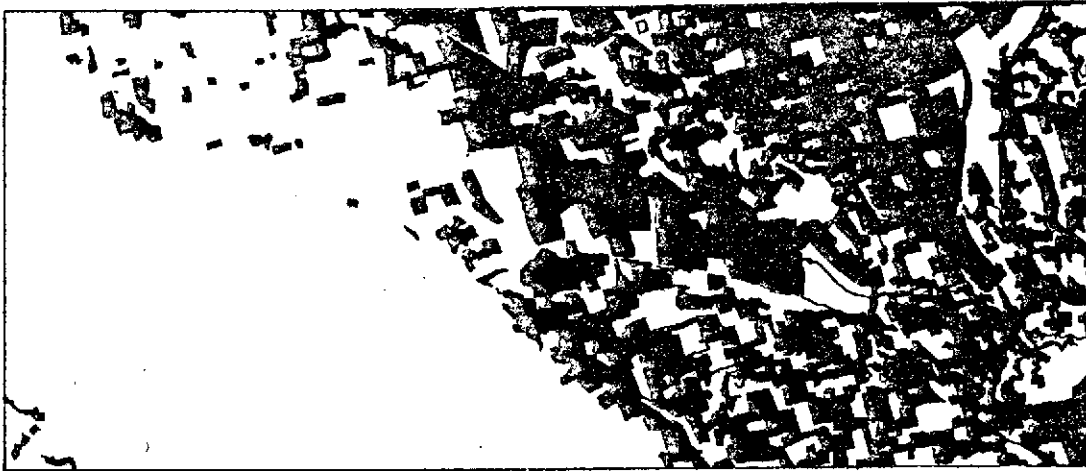
FIGURE 20



Fully automated methods employ satellite information on magnetic tape. Each ERTS picture element (known technically as a "pixle") carries information on the intensity of the sunlight reflected (radiance) from an element on the ground of approximate area 60 x 80 meters. Each pixle is identified on the tape by a triple message indicating its x and y coordinates and light intensity level. This information is processed by a computer through special software algorithms; the output is printed automatically. The cost of a fully automated facility ranges from one to three million dollars, depending upon sophistication. Less complete, lower-cost options are available.

An example of mensuration from ERTS data is shown in Figure 21, which synthesizes the key features of a test by F. J. Thomson of the Willow Run Laboratories, University of Michigan. The crop was rice: the region, the Sacramento area in California. Figure 21a depicts the rice acreage (approximately 41 km<sup>2</sup>) identified on the ERTS frame. If this area were measured just as it appears on the imagery, an error of approximately 20% with respect to the true acreage would result. Detailed computer processing reveals discontinuities within the areas shown in black in Figure 21a; breaks between fields, roads, ditches, non-producing field borders. These are shown in Figure 21b, which depicts an enlarged portion of one of the black areas. By taking these discontinuities into account by automatic processing; Thompson was able to measure the acreage of individual 50 to 100 hectare fields to within 4% of USDA's ground measurements. For the total rice acreage of 41,000 hectares, his measurement departed from USDA's by 0.25%.

The practical problem facing researchers and administrators is the cost of aerial surveys: in most cases, they exceed significantly the cost of conventional ground methods. Aircraft technology is essentially mature, thus offering only limited expectations of significant price reductions. Only



a. Distribution of Rice Crop

■ = RICE ACREAGE



... = RICE

b. Enlarged computer processed portion of a Rice-growing area, showing non-productive acreage within main fields.

FIGURE 21 Practical Example of Crop Acreage Measurement

the exceedingly low cost of satellite-derived information can cope with the cost problem.

#### 2.4 STATE OF THE ART OF REMOTELY SENSED MEASUREMENT OF YIELD

The "conventional" forecast of yield (bushels per acre, quintals per hectare) is accomplished by combining the following "normal" factors:

1. The "condition" of the crop: a judgement, based upon visual in-situ indication, of the crop's development relative to the same epoch of the previous year.
2. Past and forecasted weather phenomena, such as precipitation, temperature.
3. The time remaining to harvest.

In certain regions, additional "abnormal" factors affecting yield can be important: plant disease, pests, floods, droughts, and other non-regularly recurring phenomena.

Among the "normal" factors, the measurement and limited prediction of weather-dependent phenomena require data from hydrometeorological networks, including weather satellites. Crop condition is thus the one measurable "normal" quantity which properly falls within the sphere of Remote Sensing as defined in this report.

Current techniques for crop condition assessment from remote sensing are still experimental, although progressing at a rapid rate. Excellent results have been achieved from low-flying aircraft in localized areas. Techniques under investigation can be divided into two major categories.

a) Measurement of discernible plant characteristics, such as the number of plants per unit area, or plant crown area. These techniques require high resolution, achievable at present only from low-flying aircraft. Encouraging results have been found by USDA: the cost of the required aircraft overflights has so far discouraged operational application, at least in the

U.S.

b) Inference of plant condition from the measurement of aggregate, composite characteristics. This type measurement does not require high resolution: it is suited to both high-flying aircraft and satellites. The underlying principles are: 1) vegetal production is related to the area of leaves exposed to the sun; non-stressed plants develop larger canopies which cover more ground than less vigorous plants; 2) agriculturalists already use as measures of condition leaf area index (LAI), crown area, plant population per unit area, percent ground cover; 3) the radiometric response from the ground remains essentially constant, while that from leaves increases with plant coverage. These two responses occur at different spectral bands, and are thus distinguishable from multi-spectral sensors.

Thus, the measurement and comparison of relative reflectance in the appropriate bands, from year to year and as the season progresses, is a good indicator of plant condition, and hence of future yield.

Significant correlations for selected crops have been shown by various investigators as presented in Table 5. Before these results can be converted into operational practice, more than the one and one-half growing seasons elapsed from the launch of ERTS will have to be sampled. Nevertheless, even a cautious forecast cannot but predict that condition measurements from satellites will become operational in the relatively near future.

Significant progress is also being made in the detection and, in some cases prediction, of "abnormal" phenomena influencing yield. While no operational system has yet been implemented on a regular national basis, results of research are sufficiently encouraging to warrant the prediction that such systems will become operational in the relatively proximate future.

TABLE 5

## STATUS OF CONDITION/YIELD MEASUREMENTS BY REMOTE SENSING

Year	Result & Investigation	Technique & Accuracy	Crop	Carrier	Investigator
1966	Plant Biomass measured	Change in optical reflectance versus time	Wheat Cotton	Aircraft	Thomas, J.R., et al - USDA
1969	Preharvest yield indicators measured	Correlation to IR optical density 0.95 confidence level	Grain - Sorghum Cotton Carrots Cabbage	Aircraft	VonSteen, D.H., Wiegand, C. - USDA
1972	Yield indicated by measuring Leaf Area Index (LAI)	Ratio of two MSS bands Correlation coeff: 0.968	Corn	ERTS	Stoner, E.R., Baumgardner, M. F., Cipra, J.E., Purdue U.
1972	Grassland Biomass measured	Ratio of two MSS bands 95% accuracy	Hay	ERTS	Pearson, R.L., Miller, L.D., Colorado U., Kasemu, E.T., Kansas State U.
1973	Distribution of yield/condition demonstrated	Ratio of MSS bands	Hay, Various Field Crops	ERTS	Seevers, D.M., Drew, J.V., U. of Nebraska
1973	Yield "forecast"	3% accuracy	Wheat	ERTS	Morain, S., U. of Kansas

## 2.5 STRUCTURING OPERATIONAL CROP FORECAST SYSTEMS USING REMOTELY SENSED DATA

Most Nations possess some type of crop assessment and forecasting system. The question is whether their current system is adequate for their needs, and, if not, what degree of improvement would be important and worthwhile. This determination falls within the province of the internal policy of each Nation. Only general guidelines can be supplied, as indicated in Table 6.

If the National assessment indicates that improvements are of significant value to the Nation's economy or social goals, alternate methods for achieving increased accuracy or greater frequency of forecast should be considered and compared. At one extreme of the alternates is the intensification of currently employed procedures: at the other is the intensive use of remote sensing techniques. In between lie combinations of the two extremes. Final selection depends upon the costs, expected benefits, and other factors contingent upon national judgements and policies. The growth potential of remote sensing should be accorded proper weight in the final judgement of the system's value.

Remote sensing from satellites is at present immediately applicable to acreage measurement. Knowledge of acreage contributes a significant portion of the information needed for agricultural production forecasts. The portion represented by condition measurement and yield forecast should at present still be conducted by conventional techniques.

The technical procedure can be divided into three phases: System Planning, System Verification, Operational Implementation.

### 2.5.1 System Planning Phase

1. First, determine which crop or crops are economically or socially

TABLE 6

CRITICAL STEPS IN PLANNING IMPROVED CROP ASSESSMENT AND FORECAST SYSTEMS

- ① DETERMINE PRESENT HARVESTED CROP MEASUREMENT ACCURACY
  - compare early estimates with final estimates
  - compare final estimates with consumption and export information
  - identify important crops not now covered
- ② ESTIMATE THE SEVERITY OF LOSS ACCRUING TO PRESENT INACCURACIES
  - domestic economic loss measured by supply demand model
  - loss of foreign exchange
  - imperfect, or delayed, fulfillment of National Policy objectives
- ③ DETERMINE PRESENT AND FUTURE GOALS FOR CROP FORECAST
  - precision of forecasts desired
  - desired frequency of forecasts
  - permissible cost
- ④ IDENTIFY SPECIFIC REGIONS OR DISTRICTS WHERE IMPROVEMENT WOULD BE THE MOST POTENTIALLY BENEFICIAL
  - rank by crop, value, and error
- ⑤ DETERMINE WHICH PRINCIPAL CROP MEASUREMENT TECHNIQUES REQUIRE IMPROVEMENTS
  - rank by crop, value and forecast error
- ⑥ ESTIMATE THE WORTH OF IMPROVEMENTS VIS A VIS ADDITIONAL EXPENDITURES
  - benefit/cost with data above
  - if available data are incomplete, ratio to data of National neighbors.

worthy of more exact measurement. In general, these will be the staple crops or the high-value export crops of the Nation or region. Estimate the benefit accruing to improvement in accuracy of forecast.

2. Next, estimate from available statistics, the contribution of accurate knowledge of acreage to the precision of the overall production forecast. In the U.S., for example, acreage contributes approximately 50%; this figure can vary significantly in other Nations or regions. The statistical error contributed by acreage measurement inaccuracies, when compared to the National forecast goal, indicates the degree of improvement to be strived for in structuring the new system.

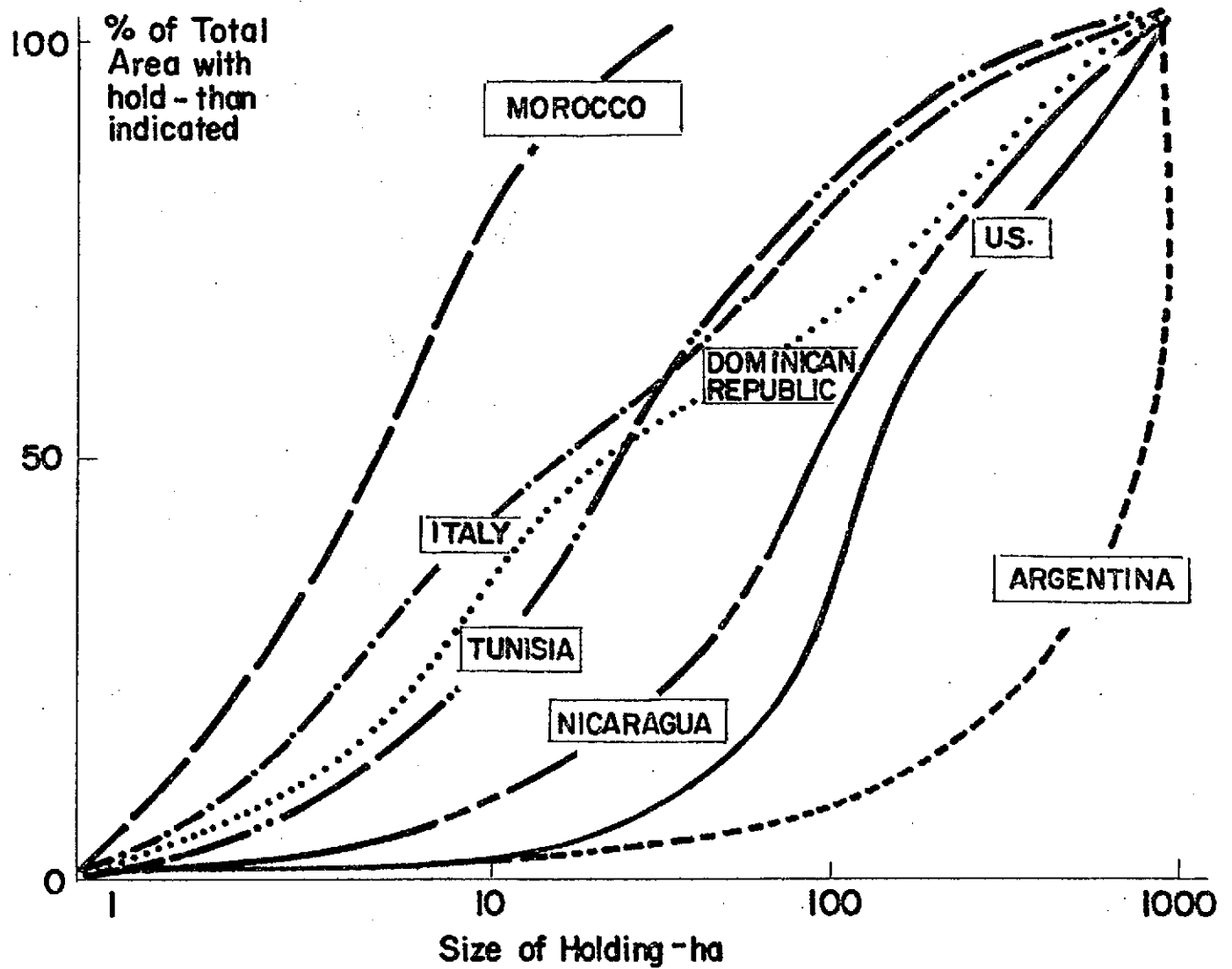
3. Determine the error in local crop mensuration to be expected from satellite information. This can be accomplished by comparing the results obtained by ERTS investigators with the particular National or Regional conditions. In general, discrimination accuracy will be high for unmixed crops or for mixed crops having dissimilar signatures.

4. Determine the probability that the crop can be observed by the satellite in a usefully short period. This is accomplished by calculating the statistical combination of satellite return frequency and regional cloud cover. Where local data is sparse, global data from sources like NOAA and/or WMO may suffice.

5. Next, remembering that the area mensuration error decreases with increasing acreage, determine the statistical and regional distribution of acreage planted with the specific crop under consideration. The distribution varies significantly among Countries: Figure 22 shows typical examples. Additional supporting data is available from various sources, principally FAO.

6. From the farm size distribution, and the estimated acreage mensuration accuracies, determine the total area which must be measured to achieve the

FIGURE 22 CROP AREA DISTRIBUTION



required accuracy. Determine the localities where such measurement would contribute most to the overall system accuracy. For example, the bulk of the crop under consideration may derive from farms in a specific area: this may be the region to concentrate upon, neglecting smaller fields dispersed throughout the remainder of the Country. Such concentration of measurements, if feasible, would serve to reduce the costs of data processing.

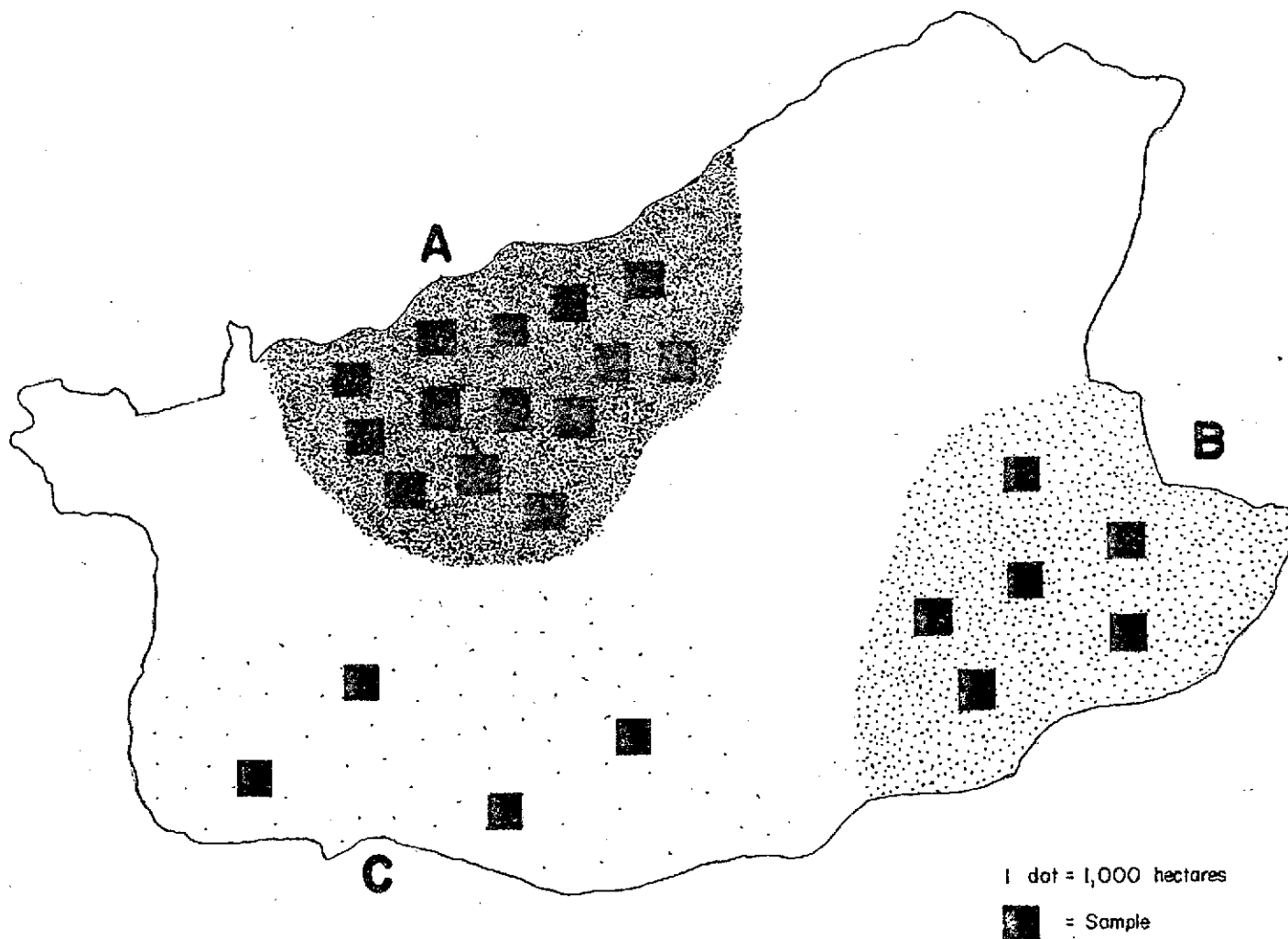
7. If the producing farms are widely dispersed, with significant contributions to production issuing from various localities, consider the appropriateness of a stratified sampling system to minimize survey costs. Its key elements are presented in Figure 23.

The advantages of considering a stratified system are twofold:

a) reduction of the cost of processing satellite data: b) a stratified system is likely to take advantage of planned technological advances in Earth Resources Satellites (for example, the NASA EOS). These will provide smaller scene sizes at higher resolutions than ERTS. For reasons explained previously, higher resolution should yield even better accuracies of mensuration than are currently produced.

8. Combine the estimates above to calculate the accuracy of acreage measurement and resulting production forecasts which can be expected from use of satellite data.

9. Calculate the cost of achieving the desired accuracy by intensifying the current ground-based crop reporting and forecast system. Costs of improved ground systems vary with local or National conditions. If literacy rate is high, and farmers are cooperative, an improved ground system could be achieved by initiating or expanding voluntary reports. Under different conditions, improvements can be achieved by increasing the number and/



EXAMPLE:

Region A produces 70% of Crop 1 - Dense Sampling

Region B produces 20 % of Crop 1 - Medium Sampling

Region C produces 10% of Crop 1 - Sparse Sampling

PROCEDURE:

Total acreage = measured crop acreage in sample  $\otimes$  inverse sample rate  $\otimes$  crop acreage to total acreage fraction  $\otimes$  historic trend.

$\otimes$  indicates statistical regression

**FIGURE 23 BASIC FEATURES OF STRATIFIED SAMPLING SYSTEM**

or skills of the specialist staff.

10. Compare the costs calculated under Step 9 above with the costs of improving the system from satellite information. Consider the following alternative options and factors:

a) The prices charged, time delays and other significant factors inherent in the preferred data-supply facility. At present, three such facilities are operating: Sioux Falls in the U.S.A., Brazil and Canada. By way of guideline, the type of products available from Sioux Falls and their costs are synopsized in Figure 24.

b) The costs of establishing and maintaining data processing facilities and staff, including initial staff training, necessary to utilize the satellite information. \*

c) The costs of procuring specialist interpretation services from contractors.

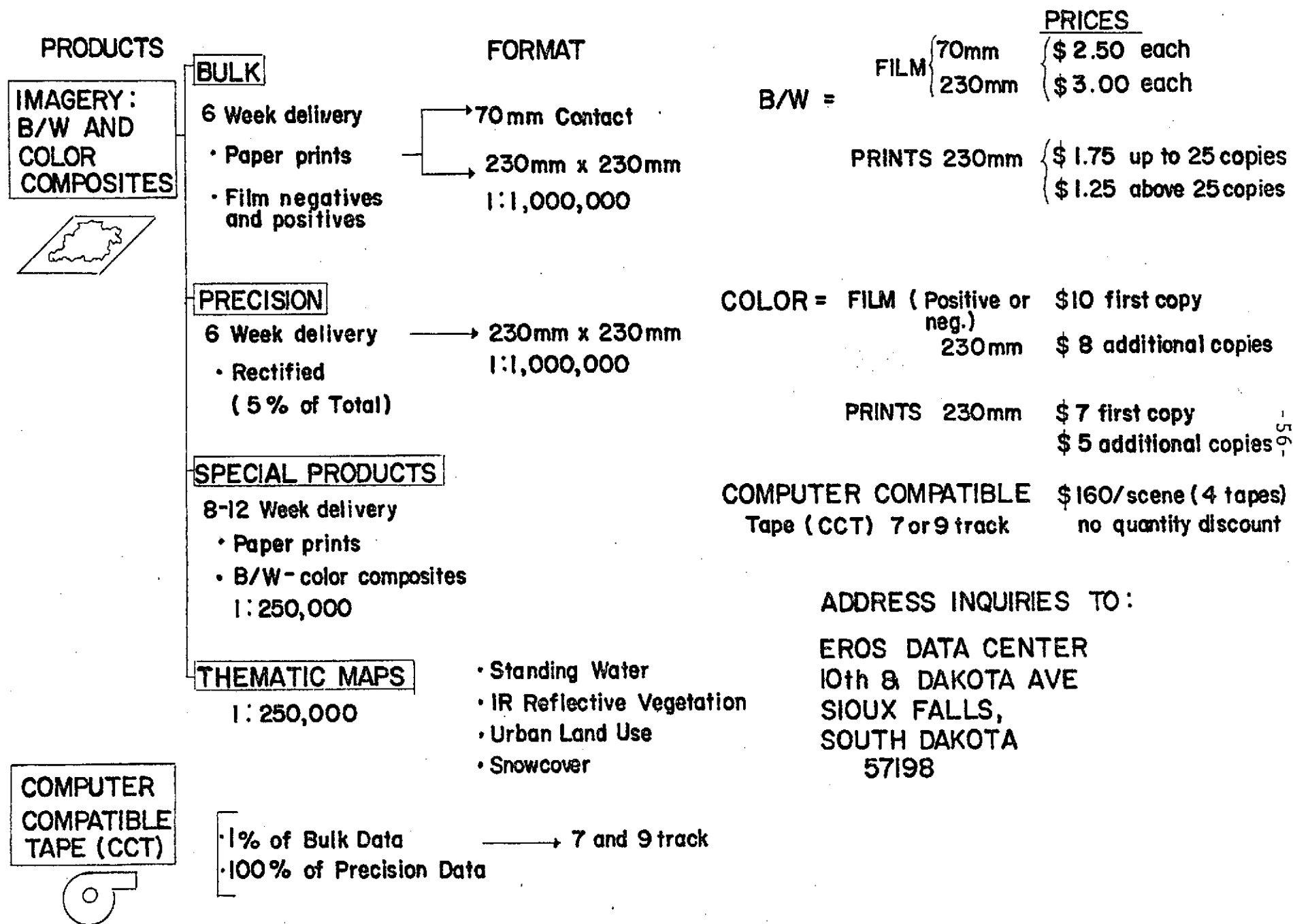
11. Ratio the costs of intensifying current ground procedures to the cost of introducing and maintaining a satellite remote sensing system. The ratio is the cost/effectiveness of remote sensing versus conventional methods. From the benefit established under Step 1 above, compute the benefit/cost.

If the calculated benefit/cost and cost/effectiveness ratios appear adequate, and stand up under administrative scrutiny, consideration should be given to engaging in a System Verification Phase prior to undertaking full operational implementation of the system.

---

\* A Report, detailing the structure, costs and performance of satellite data ground processing facilities is in preparation by the International Astronautical Federation. It is intended as a guideline for the United Nations, interested International Organizations and users. Delivery to the United Nations is planned for August, 1974.

FIGURE 24 ERTS REMOTE SENSING USER PRODUCTS AND COSTS



ADDRESS INQUIRIES TO:

EROS DATA CENTER  
 10th & DAKOTA AVE  
 SIOUX FALLS,  
 SOUTH DAKOTA  
 57198

### 2.5.2 System Verification Phase

Prior to engaging in a full operational implementation the System Planners should test the remote sensing system on a pilot basis. This will yield experience to confirm their calculations and/or to uncover and correct conditions and situations not initially contemplated.

The System Verification Phase consists in analysis of satellite data and comparison against special ground surveys of acreage planted and harvested. The duration of this phase should extend over a sufficient time period to insure statistically significant results. From 2 to 4 years appears to be a reasonable test period for most regions.

Specific objectives of the System Verification Phase are:

- a) determine the accuracy with which acreage bearing the crop of interest can be measured routinely;
- b) define the operational procedures and operator's training program required to utilize the remotely sensed data. Consideration should be given to phasing out the need for highly skilled technical personnel by developing procedures executable by normal field personnel;
- c) develop operational procedures for coordinating acreage data (remotely sensed) with yield measurements (performed in the conventional manner). This will insure that both data streams flow smoothly into the central statistical reporting and forecast facility;
- d) keep abreast of technical progress on remotely sensing crop condition. System improvements will become practical as soon as yield measurement techniques will have been tested to a sufficient degree of reliability;
- e) develop a realistic data base for costs, time delays, other system performance factors.

If the results confirm the estimations of the Planning Phase, transition to the Operational Implementation Phase can begin.

2.5.3 Operational Implementation Phase

Options available in this phase are:

a) Use the permanent services and facilities of specialized contractors, either in a foreign country or with established local residence. The contractor would procure satellite data from an existing facility. This scheme will save the initial investment outlays, but may cost more in the long run. Its drawbacks are limited transfer of technology to local personnel, and possible conflict with long-term National Policy objectives.

b) Share with neighboring Nations a data processing facility for satellite data, using data from existing Ground Reception Facility. Facilities exist in the U.S., Canada, Brazil. One is under development in Italy. Several others are being planned. Typical available products are synopsized in Figure 24.

c) Procure own satellite data processing facility

d) Share with neighboring Nations Satellite Data Reception and Processing facility.

e) Procure own Data Reception and Processing Facility

Decision among these options is a matter of cost and National Policy.

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